Conceptual Design of an Underground Subway System for the City of Asunción, Paraguay

Major Qualifying Project
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Degree of Bachelor of Science
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Abstract

The growing business opportunities in the city of Asunción, Paraguay, attract thousands of commuters daily into the city. The city's public transportation infrastructure cannot meet the demand of the users to have a proper flow of passengers into and out of Asunción. This has translated into a long and chaotic drive for the average commuter, and ever-increasing congestion in the streets of the city. This project presents a preliminary design for an underground public transportation system, to provide a fast and reliable solution, which runs for 21 kilometers, 20 meters below the street level, which will potentially reduce the commuting time by 70%. Axiomatic Design Decomposition is used to identify the fundamental Functional Requirements and Design Parameters for the design. An extensive cost benefit analysis assesses the potential benefits of the proposed solution and includes the potential reduction in travel time to the public.

Capstone Design Experience Statement

This project focused on the preliminary engineering design for an underground public transportation system in the city of Asunción, Paraguay. Currently there is another type of public transportation system being constructed in the city by the Portuguese company Mota-Engil: Bus Rapid Transit (BRT) system, which consists of buses running on an exclusive lane, separated from the rest of the traffic. The alternative design proposed in this study replaces the BRT system and analyses the reduction in commuting time of the general population with the implementation of the underground transportation system.

The design process involved the identification of the quantity and flow of the population in the city of Asunción, the selection of an area of interest representative to the project, consideration of the ground conditions to determine an appropriate tunneling construction method. The preliminary design of the system included the horizontal alignment, the number of stations, the tunnel depth and cross section the number and size of the rolling stock and lastly a cost benefit analysis of the system over 50 years. The engineering design process was preceded by an Axiomatic Design analysis to identify the relationships between the functional requirements and design parameters with consideration to aspects of safety, efficiency, economy, social, environmental, and serviceability. The design process was implemented using primarily Microsoft Excel and Acclaro software.

The proposed design was developed considering different constraints such as economic, constructability, social, political, health and safety, environmental, and sustainability. The economic constraint was given primary consideration due to the significant potential investment of this project and the long-term implications for its operational and maintenance costs. Paraguay is a country with a relatively low infrastructure budget of $900 million a year (MOPC budget, 2017). Therefore, the cost benefit analysis spanned over 50 years and used discounted cash flow analysis. In addition, the possibility of financing was considered, which would most likely consist of loans from the international community.

The constructability constraints considered the geological conditions of the city of Asunción, which is composed mainly of soft grounds. This led to the choice of using a soft-ground tunnel boring machine to bore the tunnels to minimize surface disruption during construction.

Social and political constraints were also considered A project of the type herein proposed will require the government and people of Paraguay to be intensively involved. This requires acceptance and commitment by the political process as well as by the general public, who may be paying taxes or user fees to support the economic development of this project

The proposed project promises to bring not only economic benefits to the public but also safety and environmental benefits to the city. This type of system is powered by electricity, which reduces pollution as well as car usage, which in turn leads to accident reduction and increases safety to the population.

Finally, the proposed project also addresses sustainability constraints since the system will run on renewable energy and will have a larger capacity to the present public transportation alternatives and will reduce the traffic congestion in the city.

Professional Engineering Licensure Statement

Professional licensure is an important distinction for an engineer and a proof of competency that the engineer has the credentials and specialized skills to perform its practice. It enforces standards that restrict practice to qualified individuals who have met specific qualifications in education, work experience, and exams (NSCPE, 2015). It signifies not only that an engineer understands the technical aspect but also the ethical obligations in their field of engineering and the protection of public health and safety in society (ASCE, 2015; ABET 2015). Only professionally licensed engineers are able to sign plans or offer services, as well as bid for government contracts or lead private firms (NSPE, 2015). However, not all engineers become professionally licensed due to exemptions that allow an individual to work under a Professional Engineer.

In the United States, each state has different requirements for earning a professional licensure, which are controlled by the National Council of Examiners for Engineering and Surveying (NCEES). There are however, a few steps that must be followed to become licensed. The first step is to graduate from an "Accreditation Board for Engineers and Technology" accredited program with a Bachelor of Science Degree. Around the time of graduation, the aspiring candidate must pass the Fundamentals of Engineering (FE) exam administered by the NCEES and must earn a passing score that is state dependent. By passing this exam the aspirant becomes an Engineer in Training (EIT). Following this, the EIT has to complete four years of experienced practice under the supervision of a licensed engineer. After the four years of work are completed, the EIT can take the Principles of Engineering (PE) exam. After passing the exam, the engineers can submit an application with their work and responsibilities to the state in which the license is sought. The license however, must be constantly renewed and maintained as the engineers keep advancing their careers (NSPE, 2015).

Obtaining a professional licensure is a prestigious title and a standard recognized by employers, clients, government and the public. It ensures that the work performed by the engineer is in accordance with the codes regulated by each state to perform safe and sustainable projects. Professional licensure is, in essence, assurance for the public that prepared and educated professionals are performing quality infrastructure projects in their city, and they can be trusted and accounted for them. Obtaining a license is not an easy task, and professional engineers have put a lot of effort and dedication in getting that license, which gives them pride in knowing that their work is not only recognized but earns the state-authorized engineering seal of approval. A professional engineering license also gives the individual flexibility in their own careers, since they can expand their opportunities beyond a company structure, and become a specialist or an independent consultant, and even start their own company.

Society relies on civil engineers daily, since they are in charge of laying the infrastructure we use every day on our cities, from roads, to buildings, to our own houses. These works affect the lives of everyone, and if not performed correctly, they can lead to serious consequences. It is so that a professional engineering must be accredited, licensed, and trusted to do the right thing not only in the technical aspect of their work, but be knowledgeable in the social and ethical implications of their labor. Professional licensure sets a standard to be built upon and eventually improved. Our work in this project with making a preliminary analysis and design of an underground transportation system in the city of Asunción, along with the four years we spent at Worcester Polytechnic Institute, have served as an initial step in the process of obtaining the Professional Licensure.

Authorship

In general, both members contributed with equal amount of effort to the completion of this project. The following list indicates the main contributions of each member in the report.

Antonio J. Goncalves A. – Background, Axiomatic Design, and Cost Benefit Analysis

Javier A. Lawes M. – Background, Engineering Design, and Cost Benefit Analysis

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Furthermore, we would like to thank José Tomás Rivarola, the coordinator of the construction of the BRT system in Paraguay, who kindly shared his time with us and provided us with detailed information about the BRT.

Most importantly, we would like to express our deepest gratitude to family and friends, especially for the support and encouragement provided during our professional preparation.

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1. Introduction and Problem Statement

Asunción is the capital city of Paraguay, and its metropolitan area is growing at an accelerated rate, and with it the demand for increased transportation infrastructure. As an example, the number of private vehicles has been experiencing a yearly increase of 6.4%. This has resulted in Asunción having a saturated transportation network, which translates in long lasting commutes between relatively short distances. Public transportation plays a major role on the reduction of people's private transportation usage and the alleviation of congestion in the city. However, as in many cities in the world, in Asunción public transportation is not attractive to users, since it is seen as unreliable and the buses that comprise this system are in an ever-deteriorating state due to lack of maintenance and investment. On the other hand, private transportation is becoming more and more economically accessible to the public, with the benefits of comfort and reliability. This has resulted in an increased demand for private transportation and a decreased demand for public transportation, which in turn is translated in vehicular traffic increase and more congestion for Paraguay's capital.

Public underground transportation systems have offered an alternative transportation system that effectively addresses traffic issues in cities and provide the public with an alternative for reduced travel times. With this in mind, the objective of this project is to conduct a preliminary analysis and design of a fast, reliable, and potentially economically feasible underground transportation system in order to alleviate Asunción's traffic problem.

Current review of literature shows there are underground public transportation systems operating in 135 Metropolitan areas around the world (Pyrgidis, 2016), which provide a faster alternative of transportation than those systems that operate in the surface, both public and private. In addition to providing a faster travel time for commuters, it also reduces traffic congestion and pollution on the streets of the city. Despite countless potential benefits, the implementation of a public underground transportation system requires a large investment of capital and development time. Economic analyses of multiple underground systems around the world show that economic benefits rarely outweigh the costs; only 5 Metros around the world generate income. This economic constraint is the main reason why an underground system in Asunción may have not been considered.

This project presents a preliminary design for an underground public transportation system, to provide a fast and reliable solution. Axiomatic Design Decomposition is used to identify the fundamental Functional Requirements and Design Parameters for the design. An extensive cost benefit analysis assesses the potential benefits of the proposed solution.

The end result is a tunnel that runs 21.25 kilometers, 20 meters under the city of Asunción. The expected infrastructure cost is of $90 million per kilometers, which ends up amounting to $2 billion. In contrast, the project will bring many benefits to the city and to commuters, the main one being a time reduction in the commute time from 80 minutes to 25 minutes, 70% less.

2. Background

Public underground transportation systems are present in many countries in the world, most of them very rich countries. These are located in mostly very densely populated cities, which experience heavy traffic congestion and pollution affecting the quality of life of their inhabitants, who spend a good portion of their day commuting. It is so that such systems have provided an option of faster and more reliable alternatives. In this chapter we discuss the specific case of the city Asunción, Paraguay, and give an overview on underground transportation systems.

2.1. The Heart of South America

The Republic of Paraguay, also known as the "Heart of South America," is a landlocked country that has a population of 6,461,041 inhabitants (Paraguay National Census, 2012). Paraguay's GDP is $9,779 per capita, according to the International Monetary Fund.

The country is divided into 17 departments that cover an area of 406,750 square kilometers and shares borders with Brazil, Argentina, and Bolivia (Nations Encyclopedia, n.d) (Figure 2-1). The Paraguay and Parana Rivers allow the country to trade and commerce, overcoming the country's lack of ocean access. Paraguay is one of the world's top hydroelectric producers thanks to the dams built on the Parana River, Itaipu and Yacyretá (which construction was completed in 1984 and 1994 respectively), which helps it produce enough energy to export to neighboring countries (Nations Encyclopedia, n.d).

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Figure 2-1. Geographical location of Asunción and Paraguay. Retrieved from: https://www.cia.gov/library/publications/the-world-factbook/geos/pa.html

The city of Asunción, the capital of Paraguay, which can be seen in Figure 2-1, is located in the Central Department. This city is the most populated one in the country, with 524,190 inhabitants. Its Metropolitan area, Metropolitan Region of Asunción (MRA), has 2,128,258 inhabitants, a third of the country's population (DGEEC, 2015). The MRA, shown in Figure 2-2, includes 23 municipalities, amongst which there are many important suburban cities such as San Lorenzo, Lambare, Fernando de la Mora, Limpio, Nemby, Mariano Roque Alonso, Luque, among others (World Atlas, 2017). The city of Asunción covers an area of 11700 hectares, while Metropolitan Region of Asunción spreads throughout an area of 71000 hectares. The distribution of the population in the MRA can be seen in Table 2-1.

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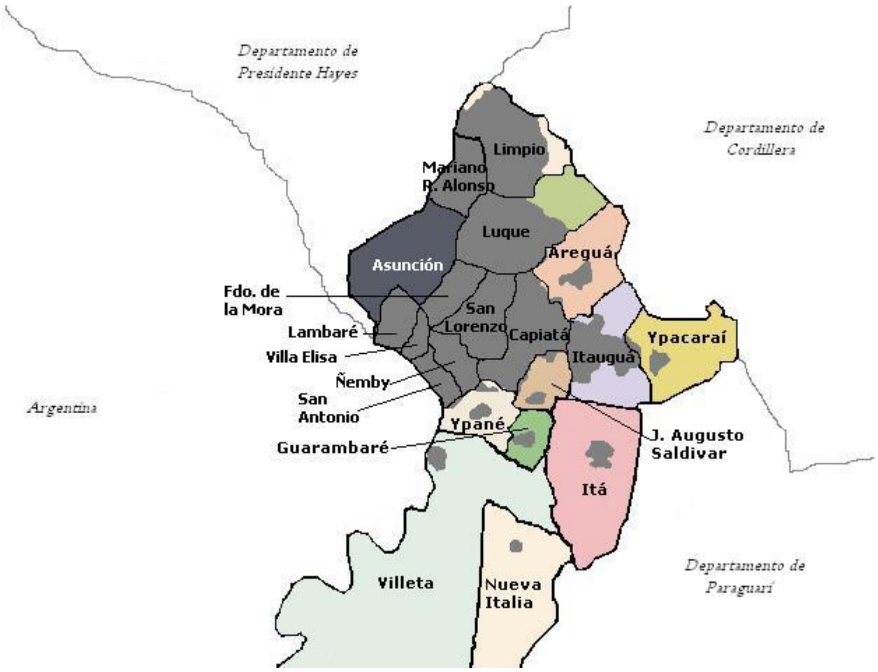

Figure 2-2. Metropolitan Region of Asunción. Retrieved from: https://www.flickr.com/photos/marcetw/5225898286/

Table 2-1. Population distribution of the Metropolitan Region of Asunción (Paraguay National Census, 2012)

City	Population	Area (km2)	Population Density (p/km2)
1-Asunción	524190	117	4480
2-Capiata	228431	83	2752
3-Luque	268247	203	1321
4-San Lorenzo	254358	91	2795
5-Limpio	136323	117	1165
6-Nemby	131048	40	3276
7-Lambare	173884	37	4699
8-San Antonio	64471	26	2479
9-Fernando de la Mora	170361	21	8112
10-Villa Elisa	77287	122	633
11-Mariano Roque Alonso	99658	50	1993
Total	2128258	907	2346

The following sections will discuss topics related to the city of Asunción itself which are pertaining to our preliminary design of an underground transportation system implementation.

These will include the demographics of the city, the present conditions of traffic that the system will aim to overcome, and the geological conditions of the city under which the system must be built.

2.1.1. Demographics of Asunción

The increase in population of the near suburban cities of Luque, Fernando de la Mora, San Lorenzo, Lambare, Nemby, and Mariano Roque Alonso have been larger than that of Asunción, creating a dispersed urban development that requires public transportation services that provide coverage to these areas. The population of Asunción itself has been slowly decreasing. It reached its peak in 2007, with a population of 531,831 people, has been decreasing ever since by 0.15% each year, and is projected to continue on that path (DGEEC, 2015). The current density of the city is of 4480 persons/km^2,while the current density of the whole MRA is of 2346 persons/km^2.

This migration has been pushed by a lack of investment in the central district of Asunción in infrastructure and equipment for transportation, drainage, green areas, and housing, among others. The influx of people has come not only from the city center, but also from other cities and towns of the country, by people looking for better opportunities. This population increase has brought with it significant vehicular congestion issues to the MRA. Between the years 1984 and 1998, the volume of traffic has increased approximately 240% (CETA 1984 and CETA 1998). The continuous growth of the peripheral cities of the MRA has affected not only traffic in those cities, but in Asunción as well, since a big number of people living in the MRA come to work to Asunción daily. This is shown in traffic studies that have been done for the public transportation system of the BRT (currently under construction), in which around 10000 people were recorded in a single hour at a single station of San Lorenzo travelling to Asunción (Logit, 2015). The increase in traffic has brought with it an increase in congestion, as previously stated, and with it longer commuting times.

2.1.2. Traffic studies

As stated in the previous paragraph, the volume of traffic had an enormous increase between 1984 and 1998. That volume has continued to increase, primarily as a consequence of the influx of private vehicles into the city. This has been accompanied by a decrease in the use of the unreliable and insufficient public transportation system. The following sections describe this phenomenon.

The last major study regarding traffic as well as public transportation in Asunción was done in 1998 and was called the "Plan CETA." This was an update to a study of the same name done 14 years earlier, in 1984, showing the progress that was made and a projection of the increase in population and vehicular demand all the way to 2015. The projections done in the Plan CETA were very accurate. It predicted a population of 2,246,000 for 2015, which actually ended up being 2,128,256, a mere difference of 5% (Tanaka et al, 1999). Currently, a BRT is being constructed in the city as an alternative to the current state of public transportation, which uniquely consists of buses. The BRT is a series of independent buses running on a differentiated and exclusive lane that does not mingle with the general traffic. This will allow the BRT buses to operate at higher speeds and reduce travel time for its passengers. On the negative side though, it will take away a portion of the street, making the space available to cars even less. Traffic studies as well as population flow studies were made in 2011 in order to plan for this system, however they encompass only the area of the city through which the BRT is projected to run (mostly the length of Eusebio Ayala Avenue all the way to San Lorenzo), as opposed to the more holistic view of the “Plan CETA,” which scope is the whole city, including Asunción itself as well as the suburbs.

2.1.2.1. Population with private vehicles and use of public transportation

In 1998, the number of households in Asunción that had vehicles was of 40,384 out of the 105,187 surveyed, representing 38.3% of the population, according to the National Census performed in 2012. From the 96,582 houses interviewed in the capital, 45.3% of them had either a truck or a car, and 15.8% had a motorcycle. If we combine these numbers, it ends up as 61.1% of the population. There is a margin of error in this number, since some of households can obviously have both a car and a bike, but it is safe to assume that the actual number of households with a vehicle has increased. That is because there have been a lot of motorcycle assembly companies established in Paraguay, which have reduced significantly their cost and made them a cost-effective alternative for transportation.

Table 2-2. depicts this increase between the years of 2011 and 2014, not only of motorcycles but also of cars and trucks (Logit, 2015). The number of private vehicles increased by 20.6%, while the number of motorcycles alone increased by 54.70%. These numbers depict how the public has been turning to private alternatives, which in turn have made the congestion of the city worse.

As an alternative to private vehicles, a fleet of buses is the only public transportation system in Asunción. The network is owned by different private companies, and the routes each company follows are established by the local government of the city. The fleet of buses is generally an old one and is frequently seen that one has broken down in the middle of the street. This has caused a decrease in the usage of them, which may have also been promoted by the decrease of costs of personal vehicles (cars and specially motorcycles). The following figures show a comparison of this between the years 1984 and 1998.

Table 2-2. Vehicle increase in the Central Department of Paraguay

Year	Cars	Trucks	Jeeps	Motorcycles	Total
2011	195920	101618	840	98510	396888
2013	222733	100612	841	133926	458112
2014	224847	100444	847	152436	478574
Increase 2011-2013	13.70%	-1.00%	0.10%	36.00%	15.40%
Increase 2013-2014	1.00%	-0.20%	0.70%	13.80%	4.50%
Increase 2011-2014	14.80%	-1.20%	0.80%	54.70%	20.60%
Yearly Increase 2011-2013	6.60%	-0.50%	0.10%	16.60%	7.40%
Yearly Increase 2013-2014	1.00%	-0.20%	0.70%	13.80%	4.50%
Yearly Increase 2011-2014	4.70%	-0.40%	0.30%	15.70%	6.40%

Mcal. Lopez Avenue is the only street in which the usage of the bus system has increased, but not by much. It can be seen how the use of the public transportation system has decreased in the other streets, especially in Artigas. This comparison dates from 1998. It was just three years ago that new buses have been starting to be noticed going through the city, and currently there is a new bus rapid transit (BRT) system being built. With that in mind, and the poor condition of buses in general, it is likely that those margins have increased nowadays.

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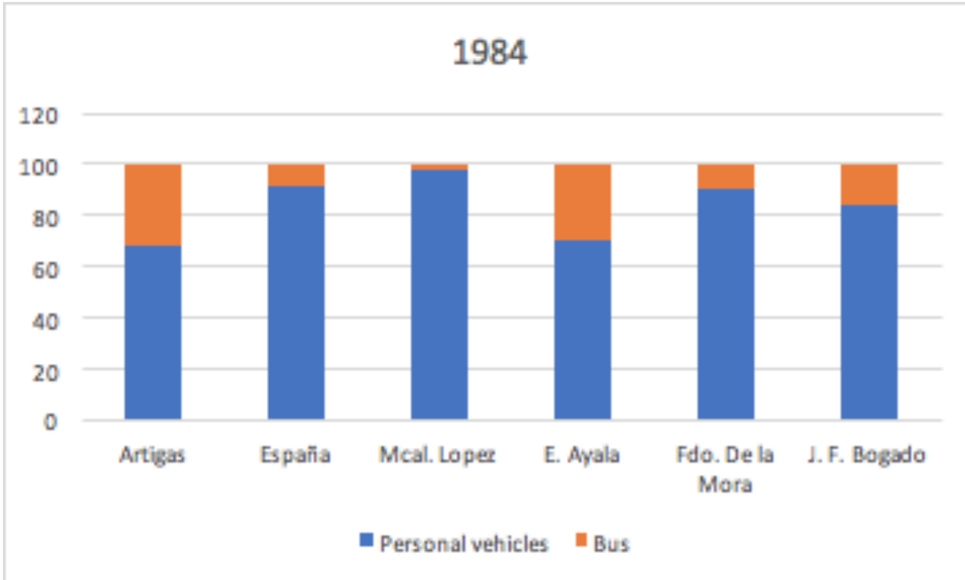

Figure 2-3. Usage percentage between personal vehicles and cars in 1984 (Tanaka et al, 1999).

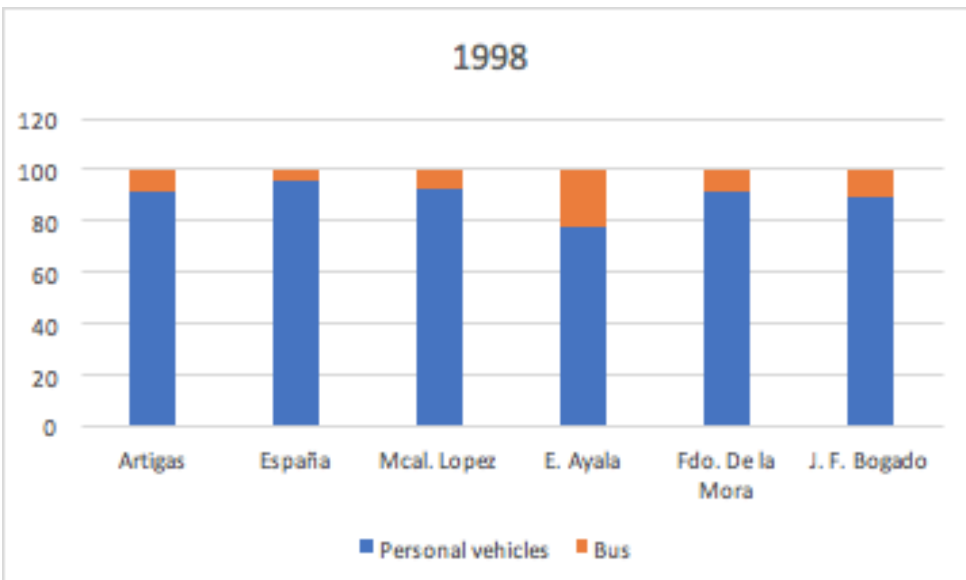

Figure 2-4. Usage percentage between personal vehicles and cars in 1998 (Tanaka et al, 1999).

2.1.2.2. Traffic Flow

The following paragraphs describe the increase in traffic flow in four "regions" of the MRA. The first constitutes the limit of the MRA, the second shows the limit of Asunción, the third shows the city of Asunción itself, and the fourth the center of the city. Those regions can be seen in Figure 2-5 (for the specific suburbs you can refer to Figure 2-2).

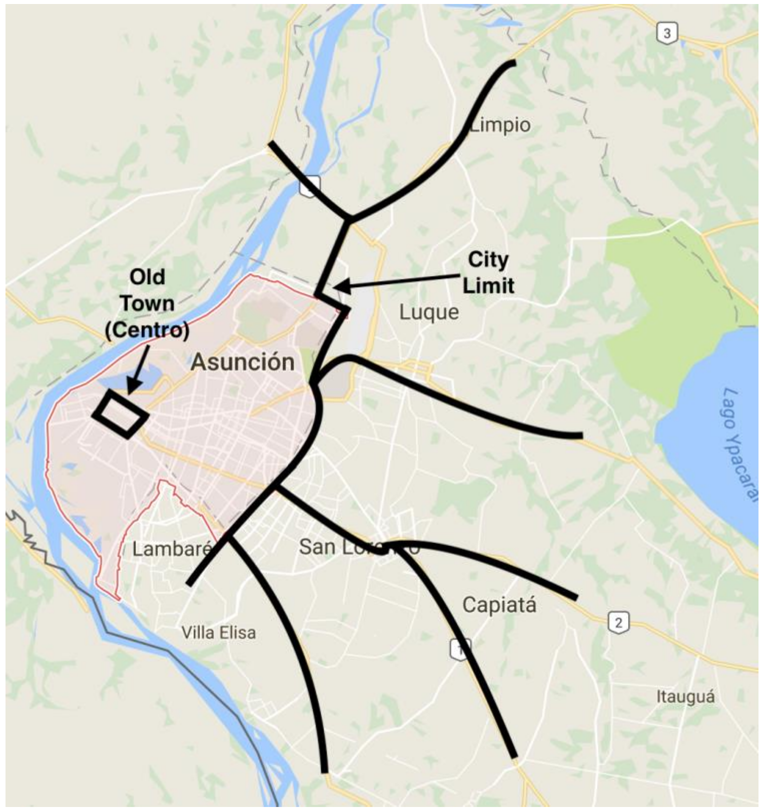

Figure 2-5. Asunción and its limits

From 1984 there has been a substantial increase in the volume of cars running through the main streets of Asunción. The “Plan CETA” presents a comparison of this volume from the previous study done in 1984 and the one from 1998. In the routes leading out of the MRA, specifically those departing from San Lorenzo (Route 2) and Nemby, the increase was of 247% and 161% respectively. This represents a total volume of 16797 cars for San Lorenzo and 4034 for Nemby, measured over a period of 14 hours (Tanaka et al, 1999).

The increments of traffic on the limit of the city were very large, and proportionally the greatest of all. The Transchaco Avenue, which exits the city on the North, had a volume larger than that of 1984 by 749% (33718 vehicles/14h), and the Mariscal Lopez Avenue had an upsurge of 573% (29245 vehicles/14h). In average the total volume of traffic in the limits of Asunción grew by 400% (Tanaka et al, 1999).

The city of Asunción presents the highest growth in terms of volume, with the Mariscal Lopez Avenue having a volume of 37600 vehicles/14h, and Eusebio Ayala Avenue having 26800 vehicles/14h. This represents an increase of 149% and 160% respectively for 1998. The Artigas Avenue, which runs parallel to the river on the north side of the city, had an increase of 230%, becoming one of the major arteries of the city, with a flow of 27600 vehicles/14h. The biggest increase though happened in the streets leading to Lambare, a city of the MRA located southwest of Asunción. This increment can be seen in the streets of B. Guggiari, Felix Bogado, and Perón, with an average increase of 338% (Tanaka et al, 1999).

The center of the city though did not present a big increase. It stayed mostly the same, the street with the highest upsurge being Paraguayo Independiente, which had an increase of 133%. But most of them had their volume stay at the same level as in 1984, and some of them actually decreased, giving a clear example of the migration of the population towards the outskirts of the city. The study also reflects time and velocity over a specific distance in major streets. This however, does not reflect the current state of the city, due to the outdated data.

Therefore, it can be seen that the problem does not arise from an increase of the population in Asunción itself, which has had a constant level in its population and even a small decline, but from an increase in the population in the cities of the MRA, a big percentage of which comes to work in Asunción. This is the driver of the increase in the congestion levels in Asunción itself.

2.1.2.3. Traffic Index

The traffic index we used to assess the traffic in the city of Asunción consists of dividing the time it takes a car to go through a specific distance of a street at a peak hour and dividing that time by the time it would take a car to go through the same distance of that street at a free flow time. Free flow means that there is no traffic or the traffic is low such that it does not influence the speed of the cars moving through that transect.

This method is used by TomTom (a Dutch company that produces traffic, navigation, and mapping products) in 390 cities across 48 countries, but Asunción is not among them (TomTom website, 2017). In order to gather data and have a comparable parameter, we used Google Maps to find out the time it would take to go through specific streets of the city. The streets chosen were General José Gervasio Artigas Avenue (1), España Avenue (2), Mariscal López Avenue (3), Eusebio Ayala Avenue (4), Fernando de la Mora Avenue (5), and Felix Bogado Avenue (6), which can be seen in Figure 2-6. This are all radial avenues, meaning they extend outward from the city's center, and were chosen because they are the main arteries of the city.

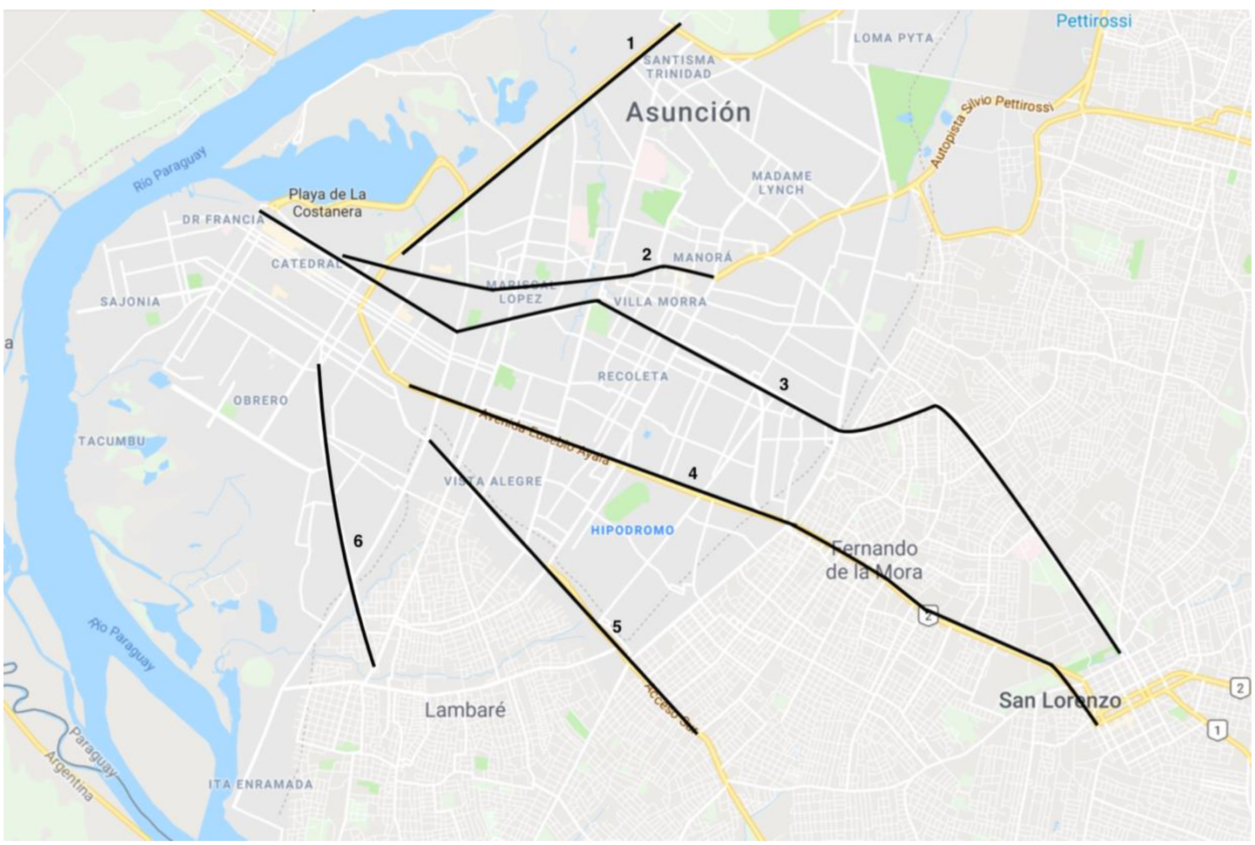

Figure 2-6. Streets of Asunción considered for the traffic studies

In order to get current data, we gathered information from Google Maps by looking at the time it takes to car owners to move around the city at certain times, which are: 6:30 AM, 12:30 PM, and 5:30 PM. We set up defined endpoints on each street, which can be seen on

Table 2-3., in order to ensure that the data from one sample to another could be compared. We ran this study from Monday, October 2 2017, to Friday, October 10, 2017, as well as on October 26, and November 8 through 10. We tried making a few variations to the time in which we ran the study to evaluate the time of worst traffic and determined them to be the ones stated earlier. The results of each of these studies can be seen in Appendix C. Table 2-4. shows an average of the data we obtained for each time slot.

Table 2-3. Coordinates taken for traffic index study

Street	Centro	Outer Asunción	Distance (km)
Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.6
España	-25.284048, -57.626659	-25.286368, -57.572481	5.6
Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	18.4
Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	11.0
Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	6.0
Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.4

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Table 2-4. Average speed and time to go through each segment of major streets

			From Centro		To Centro	
Hour of day	**Street**	**Distance (km)**	**Time (min)**	**Speed (km/h)**	**Time (min)**	**Speed (km/h)**
6:30 AM	Artigas	5.60	13.40	25.07	23.60	14.24
	España	5.60	20.00	16.80	19.80	16.97
	Mcal. Lopez	18.40	38.60	28.60	49.60	22.26
	Eusebio Ayala	11.00	31.40	21.02	37.20	17.74
	Fdo de la Mora	6.00	16.00	22.50	22.40	16.07
	Felix Bogado	3.40	8.20	24.88	10.80	18.89
12:30 PM	Artigas	5.60	17.20	19.53	12.00	28.00
	España	5.60	24.40	13.77	17.20	19.53
	Mcal. Lopez	18.40	46.00	24.00	43.60	25.32
	Eusebio Ayala	11.00	34.00	19.41	29.40	22.45
	Fdo de la Mora	6.00	15.80	22.78	17.20	20.93
	Felix Bogado	3.40	9.60	21.25	8.80	23.18
5:30 PM	Artigas	5.60	21.00	16.00	15.00	22.40
	España	5.60	29.33	11.45	23.50	14.30
	Mcal. Lopez	18.40	60.00	18.40	44.17	25.00
	Eusebio Ayala	11.00	40.83	16.16	34.17	19.32
	Fdo de la Mora	6.00	24.50	14.69	17.00	21.18
	Felix Bogado	3.40	10.17	20.07	9.83	20.75

With this data, we were able to determine the traffic index of the main streets of Asunción during the morning and evening peak hours. In order to do this, we found the percentage difference for each of the streets at each of the studied times with the time it took to cover the same distances during free flow conditions. In order to guarantee free flow conditions, we retrieved the data on Tuesday October 3, 2017, at midnight. Table 2-5 shows the traffic index for each street at each time slot and in each direction (towards or away from the “Centro”). To compare the data to the information of TomTom, we took the average traffic index during the morning in the direction towards the “Centro,” since it is the one with high traffic in the morning. On the other hand, we took the average traffic index at evening on the direction “away from the “Centro.” The respective ratios were 0.89 and 1.10. Mexico City, the leader in worse traffic conditions of the TomTom ranking, presents a morning peak index of 96% and an evening peak index of 101%. It is important to note that our analysis is based on six of the most congested streets of Asunción, while the one derived from TomTom is more comprehensive, taking into consideration less travelled streets. But it still yields an insight into the state of traffic in Asunción.

Table 2-5. Traffic index calculation

Hour of day	Street	From Centro	To Centro	Average	Morning/Evening Peak
6:30 AM	Artigas	0.34	1.62	0.98	0.89
	España	0.82	0.98	0.90	
	Mcal. Lopez	0.43	0.98	0.71	
	Eusebio Ayala	0.31	0.69	0.50	
	Fdo de la Mora	0.33	0.72	0.53	
	Felix Bogado	0.17	0.35	0.26	
12:30 PM	Artigas	0.72	0.33	0.53	
	España	1.22	0.72	0.97	
	Mcal. Lopez	0.70	0.74	0.72	
	Eusebio Ayala	0.42	0.34	0.38	
	Fdo de la Mora	0.32	0.32	0.32	
	Felix Bogado	0.37	0.10	0.24	
5:30 PM	Artigas	1.10	0.67	0.88	1.10
	España	1.67	1.35	1.51	
	Mcal. Lopez	1.22	0.77	0.99	
	Eusebio Ayala	0.70	0.55	0.63	
	Fdo de la Mora	1.04	0.31	0.67	
	Felix Bogado	0.45	0.23	0.34	

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2.1.3. Geotechnical Chart of Asunción

Paraguay is located between two sedimentary basins: the Chaco Basin on the west and the Parana Basin on the East. Asunción itself is bordered by the Paraguay River, and is intertwined by small creeks and streams. This means that the hydrological behavior of the heavy rains that seasonally affect the region (it is a subtropical region) are linked to factors such as declivity of the ground and the probability of drainage towards the bodies of water that go through the city, both the Paraguay river and the smaller creeks and streams. Figure 2-7 shows the bodies of water that run through the city, as well as the location of the main streets of Asunción.

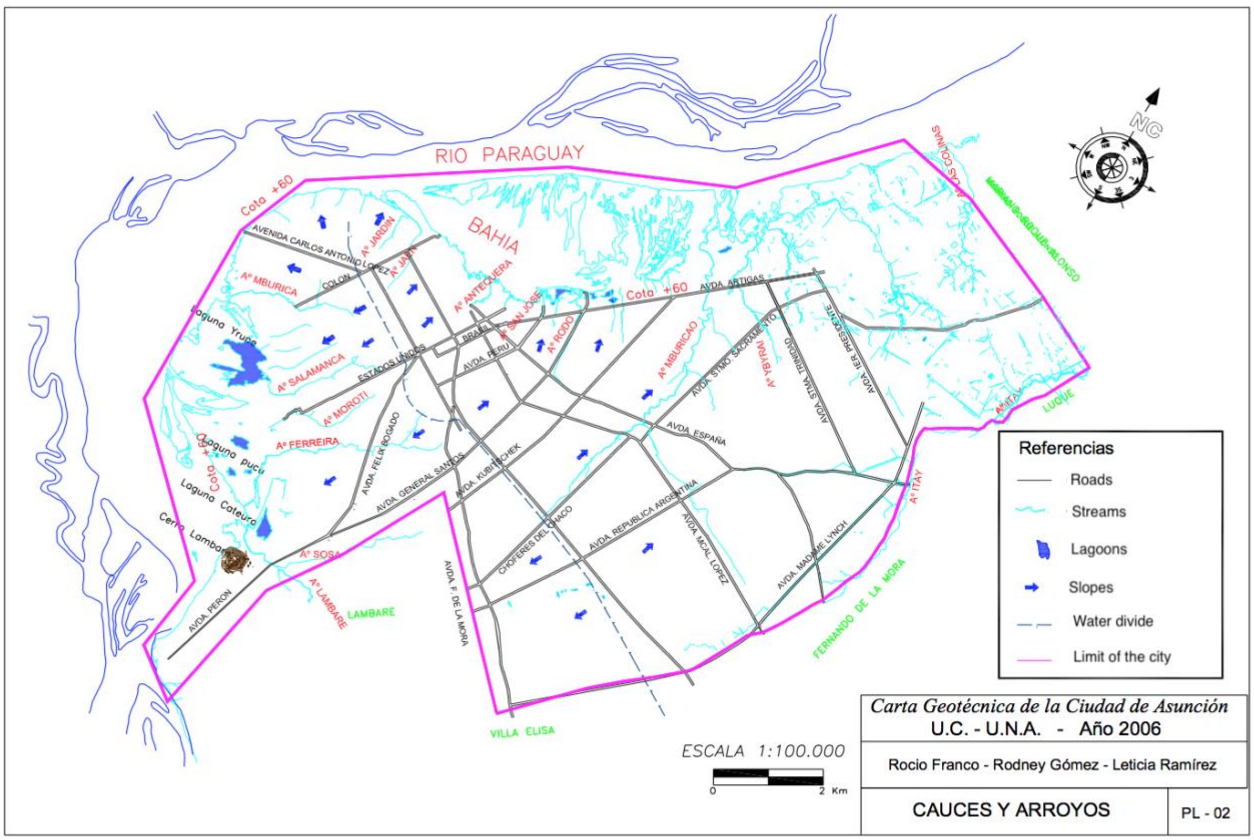

Figure 2-7. Water channels and streams of Asunción (Franco et al, 2006)

In terms of the soil of Asunción, there are two bodies that need to be taken into consideration: the surface soils and the more resistant cemented sands. The city is divided into four different zones according to their soil characteristics, which can be seen in Figure 2-8. Three different strata were defined in terms of depth. Stratum A refers to the vegetable soils, the topmost layer, which is pretty consistent throughout the area of study. Stratum B refers to the next one, and it is subdivided into other four categories, which in turn define the different zones in Asunción. The deepest stratum refers to the cemented grounds and is also pretty consistent in terms of composition throughout the four regions of the city.

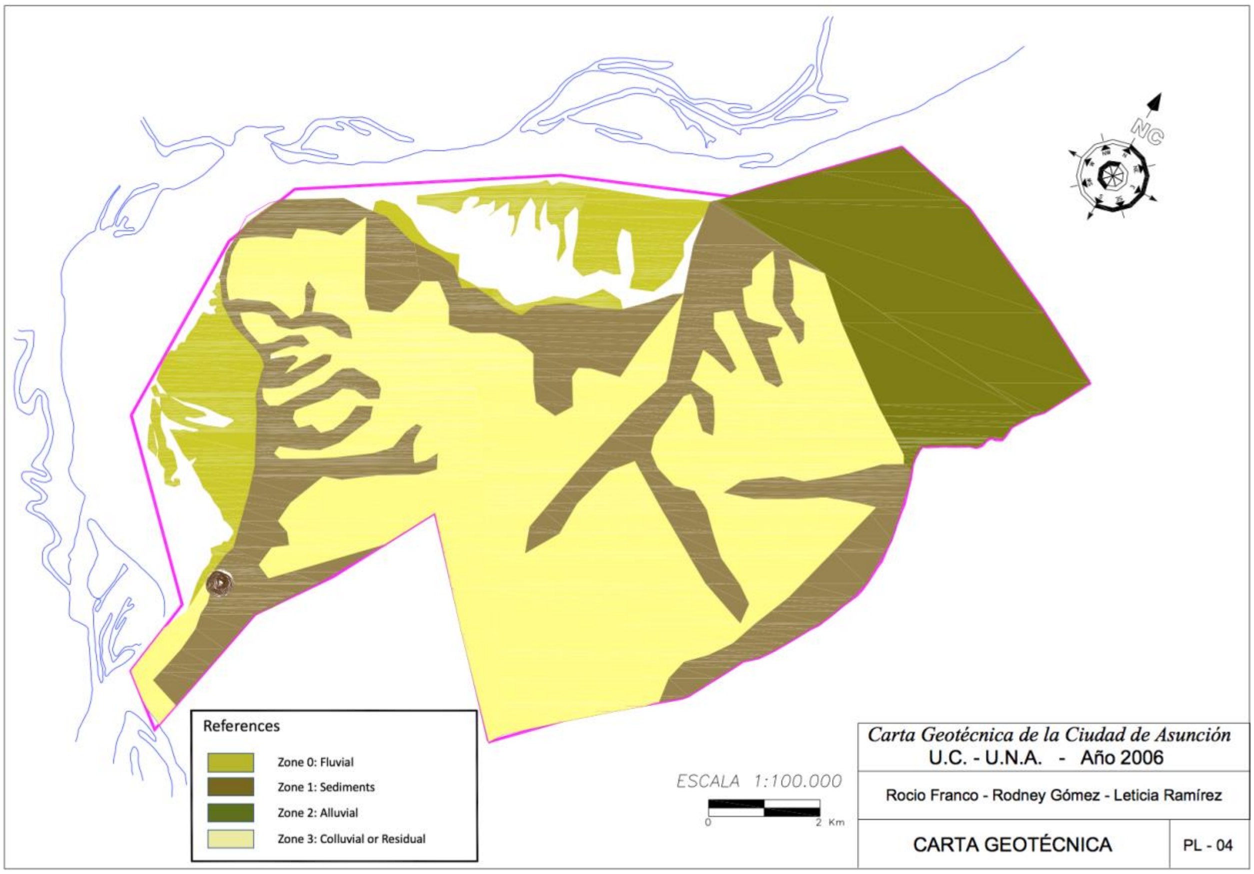

Figure 2-8. Geotechnical chart of Asunción (Franco et al, 2006)

Stratum A in the fluvial zone has a thickness ranging between 1 to 2 meters, which consists of silty sand, organic clay silt, and in a smaller proportion loamy sand. In the sediments region this stratum is composed of silty and loamy sand, but the thickness is of just 0.3 meters.

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The composition in the alluvial as well as colluvial zones is similar to that of the fluvial, but the thickness is of just 0.5 meters and 0.3 to 0.8 meters respectively (Franco et al, 2006).

Stratum C is mostly uniform across all zones. It is composed of cemented sands and the only variable is whether these sands are very dense or poorly cemented. This layer rarely exceeds the depth of 30 meters. The parameters for this layer are taken as between $\varphi = 35^{o}$ a 50^{o}; c = 0; γ =18,5 kN/m^3 and 20 kN/m^3 (Franco et al, 2006). In terms of the excavability of this type of soil, it should first be fragmented by peaks and hammers to soften it, and then remove it with shovels.

The layouts to be considered in this project are located either on the sediments, colluvial, or alluvial zones of the city. The following paragraphs will describe the stratum B for each of these regions, which is what defines them.

In the sediments zone, which corresponds to regions near old or current creeks, the stratum B is composed of silty and loamy sands, with a thickness of about 20 meters. These lie on top of very dense cemented sands, which depth varies a lot, but comes as close as 15 meters to the surface (Franco et al, 2006). The soil in this region is normally very loose, very permeable (permeability index of 10^{-2} to 10^{-5} cm/s) and the water table can be occasionally high, which can cause crumbling of the soil. To avoid this, shoring of the walls and pumping of the water must be done when performing excavations.

In the colluvial zone, the stratum B is composed of loamy sands, silty sands, and clay sands. As in the sediments zone, the soil is very loose, and its depth can go from 1 to 10 meters. The soil on this zone is moderately to not very permeable, with the permeability index ranging from 10^{-3} to 10^{-6} cm/s. In this case shoring has to be used as well, and accommodations need to be made to protect and account for near structures. The parameters to be considered for the soil in this zone are $\varphi = 30^{o}$; c = 0; γ = 16 kN/m^3 (Franco et al, 2006).

The alluvial zone is located in low regions next to elevated grounds. The drainage of alluvial regions can prove to be very slow. Its composition is of loamy sands and sandy clay that have a medium to lose density. In this region the stratum is not very deep and can be found at a depth of 3 to 5 m. This region is not very permeable, with a permeability index of 10^{-5} to 10^{-6} cm/s, and are typically saturated, with the water table being at a depth of 0.5 to 3 m. Similar to the sediments region, it is recommended to provide shoring due to the likeliness of crumbling of the ground, as well as drainage systems or lowering of the water table. The parameters to be considered for the soil in this zone are $\varphi = 27^{o}$; c = 0; γ = 15 kN/m^3 (Franco et al, 2006).

2.2. Underground transportation systems

The "Metro," according to the Oxford Dictionary, is an underground railway system in a city. It is a service that can transport up to 45,000 passengers per hour per direction. This system however, requires enormous amounts of resources to develop, with the cost ranging between $40 million to $1 billion per kilometer of construction (Pyrgidis, 2016).

There are two types of Metro, light and heavy. The differences between them are their passenger capacity, weight and length of the carts, and distance between stops. The light Metro is usually implemented in cities with a population that ranges between 500,000 and 1,000,000 inhabitants, while the heavy Metro is implemented in cities with 1,000,000 inhabitants or more.

Metro systems can be classified by their ground integration as: underground, at grade, and elevated. Based on the network's layout, Metro systems are classified into: radial-shaped layout, linear-shaped layout with or without branches, and grid-shaped layout. The layout is mainly dictated by the arrangement of the city functions, existing and planned (Pyrgidis, 2016).

Table 2-6 presents the differences between the light and heavy Metro systems on eight different categories.

Table 2-6. Heavy Metro vs Light Metro constructional and functional characteristics (Pyrgidis, 2016)

	Light Metro	**Heavy Metro**
Distance between successive stops	400 – 800 m	500 – 1,000 m
Commercial speed	25 – 35 km/h	30 – 40 km/h
Grade separation	Partial (at grade and underground)	Mainly underground
Maximum transport capacity	35,000 passengers/h/direction	45,000 passengers/h/direction
Train formation	2 – 4 vehicles	4 – 10 vehicles
Train length	60 – 90 m	70 – 150 m
Vehicle width	2.10 – 2.65 m	2.60 – 3.20 m.
Driving system	With driver or automated	With driver usually or automated

2.2.1. Driving Systems

There are 4 main categories of driving systems based on the "Grade of their Automation" (GoA). The GoA is determined by five factors or actions that are either done by a driver or attendant or are automated; these factors are: how the train operates, how it is set in motion, how it stops, how it opens and closes doors, and how it operates in an event of disruption (Pyrgidis, 2016).

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GoA1: The train is operated by a driver, who is responsible for entire driving action, and the only automation equipped to the train is Automatic Train Protection (ATP) system.

GoA2 - Semi-Automatic Train Operation (STO): The driver is responsible for opening and closing the doors and only takes control in case of a system failure. The train is equipped with ATP and Automatic Train Operation systems (ATO).

GoA3 - Driverless Train Operation: The train has no driver, but it has an attendant who is responsible for opening and closing the doors that can intervene in case of an emergency. The train is equipped with ATP and ATO systems.

GoA4 - Unattended Train Operation: The train moves automatically and all the functions, such as opening and closing doors, are performed without the need of a driver or attendant. These trains are equipped with ATO and ATP systems.

The advantages of automated Metro systems compared with Metro systems with driver are: lower operation costs due to reduction of personnel, the operation is independent from the skills and availability of a driver, increases safety due to the absence of human factor, lower energy consumption which reduces environmental impact, higher track capacity because of the higher service frequency and unified speed, and it reduces time for maneuvers at terminals which lowers delays at platforms.

Despite all these advantages, there are still disadvantages for automated Metro systems, for example, there are fewer job positions, and the maintenance cost rises because of the personnel required to maintain the system and the system's safety (Pyrgidis, 2016).

2.2.2. Guidance System

Metro trains can have two types of guidance systems: rubber-tired wheels and steel wheels. The advantages and disadvantages of these can be seen in Table 2-7..

Table 2-7. Advantages (+) and disadvantages (-) of Metros with rubber-tired wheels or steel wheels (Pyrgidis, 2016)

Rubber-tired Wheels	**Steel Wheels**
+ Low rolling noise + Greater accelerations + Ability to move along greater longitudinal gradients (up to 13%) + Reduces braking distance + Increases passenger dynamic comfort - Increases noise when starting the train - Increases energy consumption - Much lower lateral stability of vehicles (requires lateral guiding wheels) - Lower axle loads	+ Lower power consumption + Lower maintenance cost + Lateral stability of vehicles + Greater axle loads - High rolling noise - Smaller accelerations - Ability to move along smaller longitudinal gradients (up to 5%) - Increases braking distance - Reduces passenger dynamic comfort

2.2.3. Rolling Stock

Rolling stock is the term used to describe all railway vehicles, both for power or trailer. The power vehicles, also known as locomotive, are self-propelled and usually have traction motors. These vehicles can have the only purpose of pulling the trailers or can transport passengers while also containing a driver’s cab. Power vehicles can use different sources of power: steam, diesel, gas turbines, or electricity. The trailer vehicles are not self-propelled. They are divided into three categories: 1) Passenger vehicles, which are used to transport people. 2) Freight vehicles, used to transport goods. 3) Specific-use freight, are wagons use to transport a certain type of freight.

Trailer and power vehicles both have three main parts: car body (body shell), bogies (trucks), and wheelsets (axle and 2 wheels). To be considered a multiple unit trains (MU), the system needs to have the following characteristics: 1) units are made of single railcars, motor cars, and/or trailer vehicles semi-permanently coupled. 2) Driving cab at each end of the unit; driver just needs to change cab at the end of the terminus. 3) Train length can be modified by adding or subtracting units.

The cost per cart ranges between €1.3 and €2 million, or $1.6 million and $2.4 million (Pyrgidis, 2016).

Metro systems use their power vehicles with electricity, since they are in an enclosed space, and with the main purpose of transporting people, which means they have passenger vehicle. Vehicles used for Metros are usually made of semi-stainless and aluminum. The doors are either simple sliding or double sliding. The structure underneath the vehicles usually have a small wheelbase and a small wheel diameter (Pyrgidis, 2016).

2.2.4. Operations

The quality of service the Metro offers is based on certain operational parameters. Among these parameters: running through areas with high demand, short travel times, high frequency during peak hours, punctuality, proper pricing, air conditioning, passenger safety, passenger comfort, passenger capacity, clean trains and stations, service for the disable, integration with other transport services (Pyrgidis, 2016).

2.2.5. Track Layout

The determining factor for the alignment and track layout are: the need to serve locations that are located at relatively short distances from each other, and, when placed underground, the need to deal with soil settlement which can be potentially hazardous for the structures.

The track superstructure is usually made with concrete slab. This method is used instead of the ballasted track because it has much lower annual maintenance cost and easier maintenance, longer life time (50 years vs 25 years), lower height of track superstructure, ability for road emergency vehicles to move on track superstructure, and greater lateral track resistance.

On the other hand, slab tracks are more expensive than ballasted tracks, with the cost ranging from €1,165 - €1,400 ($1430-$1700) per meter of slab track as opposed to €582 - €700 euros ($700-$860) of ballasted tracks per meter. These costs refer to a single-track tunnel (Pyrgidis, 2016).

2.2.6. Tunnels

There are two categories of underground tunnels: single-bore double-track (one tunnel with two tracks) and twin-bore tunnels (two single-track tunnels) (Pyrgidis, 2016). The choice of which one to implement is determined by geological and local conditions, such as available overlying area and soil quality. As stated before, the overlaying soil in Asunción is soft, and the different types of tunneling methods are cut and cover, tunnel boring machines (TBMs), New Austrian Tunneling Method (NATM), and tunnel jacking.

2.2.6.1. Cut and cover

Cut and cover is a common technique for shallow tunnels. It consists of a cast in place concrete structure installed on an excavated trench at surface level, which is later covered. It can accommodate changes based on the shape the tunnel needs to take, it being non-uniform, or having a width that is constantly changing. It is normally used for the stations of the subway system (these however can also be built completely underground). This method is normally more economical than the alternatives when the depth is around 10 to 12 m (30 to 40 ft.), however it has been used for depths of up to 30 m (100 ft.) (Pyrgidis, 2016).

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The methodology can be performed in two ways: the bottom up approach and the top down approach, which can be seen in Figure 2-9. In the bottom up approach, the retaining walls are installed, the soil is excavated to the desired depth and horizontal struts are installed to provide lateral support to the opening, and finally the structure is built from the bottom up. In the top down approach, the retaining walls are first installed, and the structure is built as the excavation reaches the different strut levels, leaving an opening in the structure to keep going down.

The negative aspect of the cut and cover method is that it causes disruption to daily life, and the traffic that goes through the affected area needs to be deviated until it is completed. The surface disruption however, can be minimized by placing decking over the excavation to restore traffic.

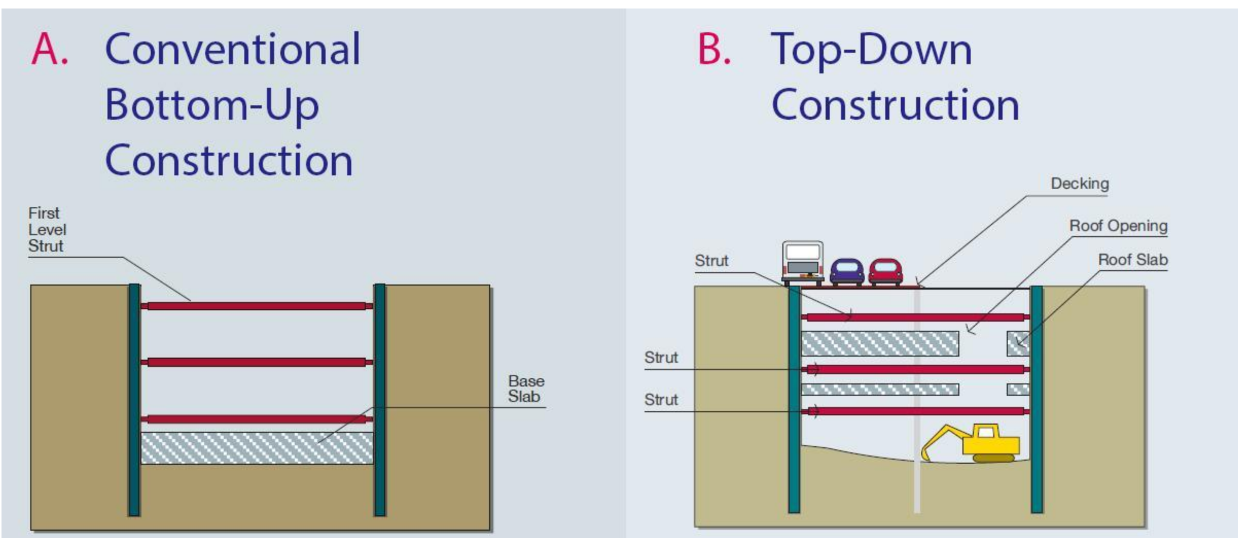

Figure 2-9. Cut and cover a) bottom-up approach and b) top-down approach. Retrieved from http://www.railsystem.net/cut-and-cover/

One of the most recent subway systems built using the cut-and-cover approach was the Canada Line of Vancouver, Canada. It used several methods for different parts of it. A portion of the trajectory went through Cambie Street. The section going between 25th and 49th street, which are 3.1 km apart, was dug between February 23rd and June 7th, making for an average tunneling rate of 1 km/month.

2.2.6.2. Tunnel Boring Machine

The Tunnel Boring Machine (TBM) is used in the case of deeper and longer tunnels. As the TBM passes through the ground, a precast concrete segmental lining forms the tunnel behind the machine. The segments are waterproof and act as the structural support system. These machines come in various diameters that can go up to 19.25 m (Davidson et al, 2014). TBMs are used for both rock and soft ground, the majority being implemented for hard-rock excavation. However, for soft-ground excavation, the two major types of TBMs are the earth pressure balance (EPB) or the slurry type shield machines. The EPB (Figure 2-10 top) has a cutter rotary head that penetrates through the ground and removes the soil through a conveyor belt. It performs better on silty grounds. On the other hand, the slurry machine (Figure 2-10 bottom), which also has a cutter rotary head, removes the extracted material by injecting bentonite, which creates pressure on the chamber of the removed debris in order to extract it. The slurry machine is ideal for loose water-bearing soft grounds such as the one present in Asunción. One of the basic principles of this technique is that the distance from the ground surface should not be less than one bore distance (defined as one diameter of the bore, which is about 6 m for single-track tunnel and 9.5 m for double track tunnel) from the upper limit of the tunnel. As opposed to cut and cover method, the TBM does not create a significant disturbance on traffic.

Hamed Hashem Pour (2016) analyzed the productivity rate of tunnel boring machines based on 23 case studies. He concluded that the average productivity for sandstones is 27 m (90 ft) per day, for limestone 24 m (80 ft) per day, and for granite 17 m (55 ft) per day, considering 8 hours of excavation per day. These are all rocks. Gordon Clark, from the University of

Washington, has similar numbers for the rocks, and states that for soft ground the average distance per day is of 9 m (30 ft). The study also indicated that the average productivity rate in urban areas is of 80 ft per day, and that the higher the diameter of the tunnel the lower the productivity (although this does not have a big effect).

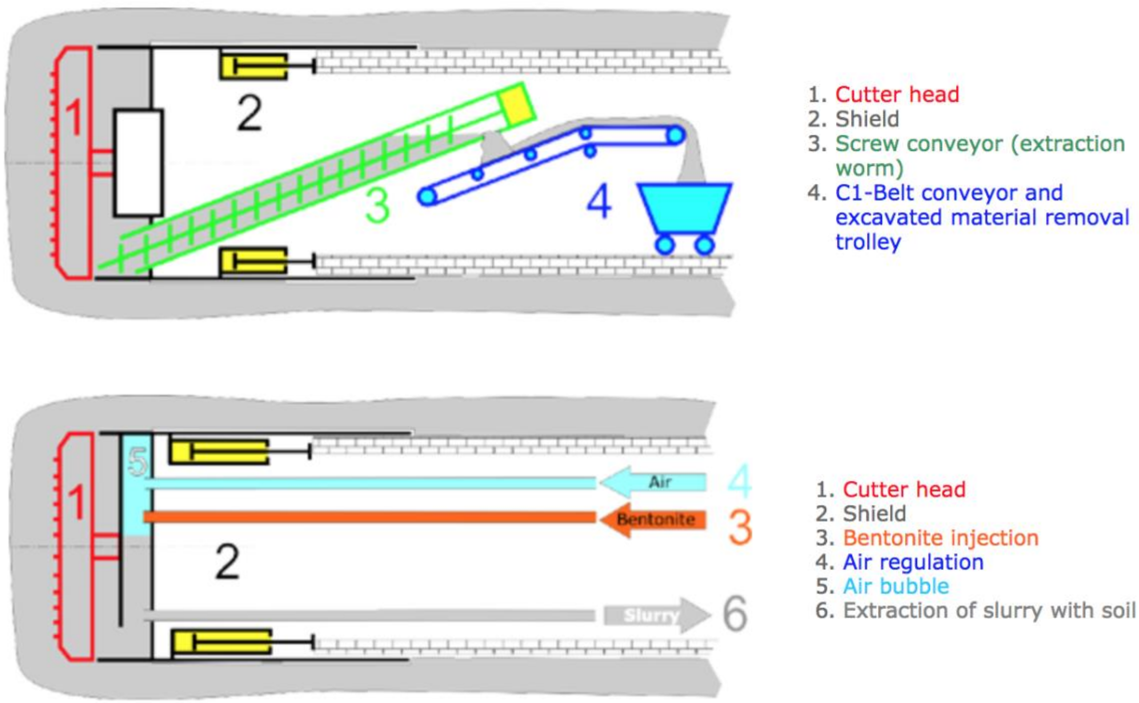

Figure 2-10. Earth Pressure Balance TBM (top) and Slurry Type Shield TBM (bottom). Retrieved from http://www.nfm-technologies.com/-Soft-ground-machines-.html

2.2.6.3. New Austrian Tunneling Method

The New Austrian Tunneling Method (NATM), also known as adaptable excavation method, is good for shorter tunnel sections, non-circular tunnels, or tunnels with variable geometry. It provides a cost efficient, flexible, and safe tunneling option. The process consists of excavating a section of the tunnel (either full-face or partial-face excavation through drill-and-blast methods), adding rock bolts, welded wire mesh, and pouring shotcrete to provide support, before going on to the next section. It also monitors the rate of deformation on the supports, which can tell the engineers whether more material needs to be added.

2.2.6.4. Tunnel jacking method

Lastly, the tunnel jacking method refers to the construction of monolithic, rectangular concrete box section that runs under surface areas with uses such as railways, major roadways, and airport runways. However, this method is very expensive and used only under special circumstances.

2.2.7. Metro Stations

The Metro stations are a main component of the system since they constitute the access of the public to the trains. There are three types of stations simple stations, transfer stations, and interchange stations. The simple stations serve only the area near it. The transfer stations have the same function as the simple stations, however they also serve to transfer between different lines of the same Metro network. The interchange stations, aside of an access to the system in the area near them, also serve as a connection with other public transportations systems, such as buses. The stations can be either underground or built on the surface, with the underground stations being 4-6 times more expensive, and they increase the total cost of construction by 25%-30% (Pyrgidis, 2016).

The stations are going to be located in the system based on the locations that have a high travel demand. They should be placed in order to reduce the walking distance of the users, and also consider locations in the city with an elevated number of commuters, such as universities, stadiums, and hospitals. According to Pyrgidis (2016), the location of the Metro stations depends on the following factors:

- The trip characteristics of users: determines the number of potential users, and where, when, and how frequently they are going to be using the system.
- The accessibility of stations: which should be placed at intersections of main roads, and at locations of high population density, such as stadiums, hospitals, etc.
- The availability of space for the constructions of the stations: even though some stations, if not all, are going to be located underground, the availability of a space with enough surface area is necessary to perform the excavation.
- The distance between stops: an average distance between two successive stations is necessary, however this distance is going to be shorter at areas of high population density, and longer at areas of low density.
- The connection to other public transport modes: as discussed earlier, the stations should be placed in locations that allow the transfer to alternative transportation systems.
- The terminals: these should be placed in locations that also allow the connection to alternative transportations systems, but at the same time have enough space such that it can allow trains to maneuver, be parked, serviced, and cleaned.

2.2.8. Depth of construction

The depth of construction for both tunnels and stations is impacted by several factors. First of all, the characteristics of the soil, that must be determined through geological and geotechnical tests. These studies will also determine the groundwater zones in the areas where construction is planned. The soil is a strong factor when determining the technical feasibility of the construction depth. The public utility networks is another important consideration, since they include the water supply, sewage sanitation, gas supply, fuels, the electricity grid, and telecommunications network, which are all going to affect the construction of the Metro system, which in turn must accommodate the presence of these factor and be built around their existence. Another big component affecting depth are the overlying building. If the Metro system is too pass under these structures, studies must be done to assess the displacement of the ground under them, and plan to support it accordingly (Pyrgidis, 2016).

Another factor affecting depth is seismicity. This however is not a problem in the city of Asunción, since it is not located in an earthquake prone region.

2.2.9. Benefits

Underground Metros offer fast, safe, comfortable, and inexpensive access to different areas of a city. Since they are underground constructions, they have three-dimensional freedom which is rarely found on the surface. Underground space is available almost anywhere, which helps install infrastructures that would be hard to install above ground. Another benefit of the underground space is the protection it offers, which ranges from mechanical, thermal, acoustic, and hydraulic protection to protection against natural disasters, nuclear wars, ultraviolet rays, electromagnetic pollution, and massive solar storms (Goel, 2012).

Metro systems have the flexibility of crossing hills and rivers, without affecting their natural properties on the surface. Additionally, they reduce traffic jams due to the fact that they are high capacity transportation systems which reduces the use of cars. This has positive effects on the environment, because it reduces carbon emissions and noise pollution, and on the population because it reduces commuting time, saving man hours. All these without disrupting the integration of the city's buildings, monuments, and bridges.

Another positive aspect of this system is the financial benefit it represents. The installation of a Metro increases the value of adjacent land near the stations. Also, it creates revenue from the tickets purchased. Moreover, a system of this magnitude creates jobs, both when being constructed and when operating.

2.3. Impact of the Project

A Metro would have a positive impact in the city of Asunción, especially considering its current public transportation system situation. Asunción currently has a saturated transportation infrastructure, with an increasing demand of 4.7% for cars and 15.7% for motorcycles per year in the last few years as seen in

Table 2-2. This means a constant worsen of the transportation network of the city and its metropolitan area, which is translated into a longer commute for the workers trying to get in the city, higher pollution levels, and an increasing amount of accidents. The implementation of a Metro would bring a wide range of benefits, including all those previously mentioned in section 2.2.9, but more specifically to Asunción, it would reduce commuting time by 70% for the users of the system. Additionally, a Metro would reduce traffic, noise pollution, and air pollution. Moreover, this system will help the economic activity by offering access to the city for a low price, lower than the cost of owning a car, as seen in Table 4-4. The design and specific benefits of the implementation of the Metro system will be discussed in the following sections. The following chapters discuss the implementation of such a system, aided by the use of Axiomatic Design, and contains the engineering design as well as a cost benefit analysis.

3. Axiomatic Design

3.1. Overview

Axiomatic Design (AD) is an engineering approach of design based on two axioms: independence axiom and the information axiom. An axiom is a self-evident truth or fundamental truth for which there is no counterexamples or exceptions. It cannot be derived from other laws of nature or principles. The independence axiom requires the independence of the functional requirements (FRs), and the information axiom aims at minimizing the information of the design. Axiomatic Design decomposition demands that the Functional Requirements that satisfy the customer must be collectively exhaustive, mutually exclusive, and stated in minimum form.

This design method attempts to reduce nonproductive iterations by filtering the bad ideas early in the process, which results in channeling the effort of the designers, since only the best ones will be taken in consideration (Suh, 2001). This results in teams making correct decisions, lower manufacturing costs, shorter lead times, improved quality of products, simplification of complex systems, and simplification of product service and their maintenance. The first step for Axiomatic Design is knowing the customer needs, followed by defining the problem, and finally conceptualizing the solution, which must satisfy the FRs using design parameters (DPs) which may be limited by certain constraints. The Design Parameters are the key physical variables in the physical domain that characterize the design that satisfies the specific FRs. The Constraints are the bounds on acceptable solutions. There are two kinds of constraints: input constraints and system constraints. Input constraints are imposed as part of the design specifications. System constraints are constraints imposed by the system in which the design solution must function.

Axiomatic Design offers a solution to optimize and checks the results to see if there are unwanted interactions between FRs and DPs (Suh, 2001).

3.2. Decomposition

The team determined the functional requirements that this project had to meet to successfully and efficiently implement a Metro system in the city of Asunción, Paraguay through the use of Axiomatic Design. It was used to specifically determine the functionality of the design, define its most effective location to implement, and outline the estimated budget needed to make this project possible. The Axiomatic Design decomposition was performed by using Acclaro Software, and guided the team to determine the most cost-efficient, most effective methods to construct the Metro system and the ideal layout design to satisfy the city's demand for transportation.

This section will show the Functional Requirements and the Design Parameters required for the design of an underground public transportation system in Asunción, Paraguay. FR0 needs to be properly defined in order to address the problem with its original intent. In this case, the goal is to design an attractive underground transportation system. This is stated at the top level of the FRs and DPs:

FR0 = Provide a preliminary design of a fast and reliable public underground transportation system.

DP0 = Design of a fast and reliable transportation system.

The first level FRs can be seen in Table 3-1. These are the main requirements this Metro system needs to satisfy.

Table 3-1. First Level of Functional Requirements

FR0 = Provide a preliminary design of a fast and reliable public underground transportation system.
FR1 = Provide a secure public transportation alternative.
FR2 = Provide an efficient public transportation alternative.
FR3 = Provide movement between defined end points.
FR4 = Produce a system that operates within a certain budget.
FR5 = Improve the socio-economic condition of the city.
FR6 = Alleviate the environmental impact on the city.

These were then paired with their respective Design Parameters (DP). The DPs can be seen below.

Table 3-2. First Level of Design Parameters

DP0 = Design of a fast and reliable transportation system.
DP1 = System that provides a safe public transportation alternative.
DP2 = System that provides an efficient public transportation alternative.
DP3 = System that moves the public between defined endpoints.
DP4 = Design a system that can operate within a certain budget.
DP5 = System that supports the socio-economic development of the city.
DP6 = Reduction of environmental impact on the city.

The Independence Axiom states that the proceeding domain requirements must be independently satisfied by the next domain (Park, 2010). After identifying the Functional Requirements and the Design Parameters, the team proceeded to determine which DPs had an impact on which FRs. In Figure 3-1 it can be seen that if the DP has an impact on one or more

FRs, it will be indicated with an “x”, where as if it does not, it will be marked with an “o”. After a first level decomposition, a decoupled matrix can be observed. It is considered a decoupled matrix because the Design Parameters affect more than one Functional Requirement, and it also satisfies the Independence Axiom. It is important to note that the order of the functional requirements is important to maintain the matrix decoupled. The more DPs that affect an FR, the more critical that FR becomes, making the improvement of the socio-economic condition of the city the most critical one. On the other hand, the most critical DP is the one affecting the most FRs. In this case there are three, which are designing a system that provides an efficient transportation alternative for moving people between defined endpoints, while operating under a certain budget.

The Axiom tells us that each DP should independently satisfy its corresponding FR. The desired relationship FR-DP is independence. The second level FRs and DPs are defined based on their corresponding parent FR or DP. In Figure 3-2, the first and second level FRs and DPs are shown.

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	DP0: Design of a fast and reliable public transportation system	DP1: System that provides a safe public transportation alternative	DP2: System that provides an efficient public transportation alternative	DP3: System that moves the public betwen defined endpoints	DP4: Design a system that can operate within a certain budget	DP5: System that supports the socio-economic development of the city	DP6: Reduction of environmental impact on the city
FR0: Provide a preliminary design of a fast and reliablc public underground transportation system	X						
FR1: Provide a secure public transportation alternative		X	O	O	O	O	O
FR2: Provide an efficient public transportation alternative		O	X	O	O	O	O
FR3: Provide movement between defined end points		O	O	X	O	O	O
FR4: Produce a system that operates within a certain budget		O	X	O	X	O	O
FR5: Improve the socio-economic condition of the city		O	O	X	X	X	O
FR6: Alleviate the environmental impact on the city		O	O	O	O	O	X

Figure 3-1. Axiomatic Design Matrix

	[FR] Functional Requirements	[DP] Design Parameters
0	Provide a preliminary desin of a fast and reliablc public underground transportation system	Design of a fast and reliable public transportation system
1	Provide a secure public transportation alternative	System that provides a safe public transportation alternative
1.1	Offer a comfortable means of transportation	Comfortable rolling stock
1.2	Offer a safe transportation method	Safe transportation method
2	Provide an efficient public transportation alternative	System that provides an efficient public transportation alternative
2.1	Maintain high frequency of arrivals and departures	System with high frequency for arrivals and departures
2.2	Provide a punctual system	System that is punctual
2.3	Reduce non-value added time of workers	Reduction of non-value added time of workers
3	Provide movement between defined end points	System that moves the public betwen defined endpoints
3.1	Place stations with accordance to travel demand	Design of a station network that complies with the public demand
4	Produce a system that operates within a certain budget	Design a system that can operate within a certain budget
4.1	Decide between light and heavy metro	Light or heavy metro
4.2	Determine the combination of excavation methods to build the system (combining disruptive and nondisruptive)	Combination of excavation methods
4.3	Construct tunnels	Tunnels construction
4.4	Construct stations	Stations constructions
4.5	Purchase rolling stocks	Purchase of rolling stocks
5	Improve the socio-economic condition of the city	System that supports the socio-economic development of the city
5.1	Weigh the cost difference between the new system versus current private and public transportaion systems	Comparison of current private and public alternatives to proposed system
5.2	Examine the travel time difference between the proposed system and current transportation systems	Comparison of travel time difference between proposed a;ternative and current
5.3	Evaluate the reduction of car usage	Analysis of reduction of car usage
5.4	Facilitate commerce	Foster of commerce
6	Alleviate the environmental impact on the city	Reduction of environmental impact on the city
6.1	Decrease air pollution due to emissions	Reduction of air pollution due to alternative system
6.2	Lower noise pollution	Reduction of noise pollution due to alternative system

Figure 3-2. Axiomatic Design Decomposition

Axiomatic Design helps keep a clear vision throughout the project regarding its objectives. It also helps the decision-making process by discarding less valuable ideas, concentrating resources and time in the more viable ones. Moreover, it provides a graphical representation of all the functions a design needs to have in order to meet the customer's needs when delivering the final product, while always following the constraints and parameters stablished or necessary. In this case, it helped us identify which design, construction and excavation methods, and layout were optimal to meet our objectives.

4. Engineering Design

The main objective behind this project is to propose a fast and reliable underground transportation system that would provide the city with a swifter, more economic and secure public transportation. This chapter presents the preliminary design of such system. The initial concepts for the design were first analyzed following the Axiomatic Design methodology as presented in the previous chapter.

Through library research and in-person interviews (as well as email conversations) with staff members of the Ministry of Public Works and Communication of Asunción (J.T. Rivarola, personal communication, August 10, 2017), we came across studies that have information regarding the demographics of Asunción, traffic growth patterns, passenger flow, vehicle ownership, public transportation usage, public transportation availability, among others. Even though these data sets are outdated, we used them as a point of comparison and compared them with the current state of both traffic and population flow in the city. The projections of the current state have been determined based on outdated information, and then projected to present day utilizing growing trends of the population and other studies done for more recent projects in Asunción.

These projects, mainly the most recent ones, are about the BRT line currently being built in Asunción, which is discussed in more detail in Section 4.2. This data allowed us to evaluate the operational costs of the system, determine the minimum yearly capacity that our system required, which led us to determine the minimum number of trains we needed per year. It also led us to evaluate the impact this system would have on society by analyzing the reduction in the environmental impacts and accidents, which are discussed in Chapter 5.

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In addition to this, we considered several case studies and focused on the ones from Beijing, China, to aid us in our technical design considerations. We chose Beijing due to the similarities in the ground conditions and in the labor cost to that of Paraguay. The following sections explain the mentioned aspects of the engineering design of our proposed underground system.

4.1. Beijing: a model for the system

Beijing has 19 different subway lines that span over 574 kilometers. The soil in Beijing is very similar to Asunción's, being composed of silty sand, silts, silty clay, and clay, with the water table relatively high (at a depth that ranges between 10 to 25 m), as can be seen in Figure 4-1(Fang et al, 2012). In a study done by Fang et al, which researched shallow tunnels for subway systems, three lines were studied, - lines 4, 5, and 10 - the three of which were opened in 2009, 2007, and 2008 respectively. These were built using a shield tunnel boring machine, with very high efficiencies, averaging a boring rate of 12 km per year with a cost of $82 million (this sum considers all the costs regarding the construction of the tunnel, including the tunneling and the infrastructure) (Chang, 2013). In view of the similarities the soil of Beijing presents to that of Asunción, as well as the similar labor cost, – in Beijing the minimum wage is of $302 while in Asunción it is of $368 – we decided to take a similar approach in design and construction to that in Beijing and use their costs as a parameter for our own system.

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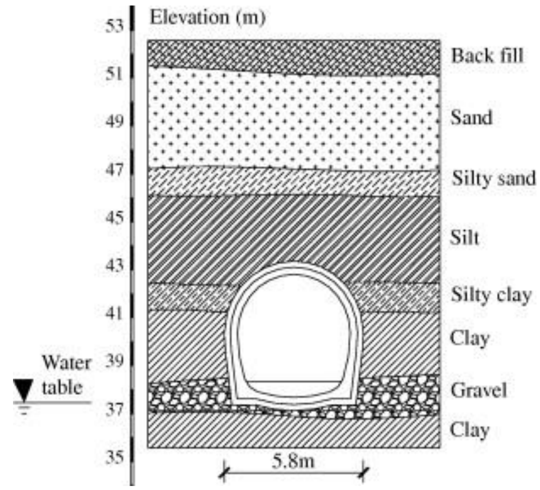

Figure 4-1. Geological profile of a tunnel section in Beijing (Fang, 2012)

In order to determine the infrastructure cost that corresponds to stations and to the tunnel in between them, we took the consideration stated in 2.2.7 that the stations account for 30% of the overall construction cost. The Beijing Line 4 has 24 stations, from which we determined the actual cost of each station. The other 70% accounts for the cost of the tunneling between the stations and based on the total length of 28.2 km of the subway line 4 of Beijing, we were able to determine the cost per linear km of tunneling. The specifics of the calculation can be seen in the "Metro Infrastructure Costs" in Appendix B. Based on this analysis, the estimated cost per station in Paraguay is of $35 million, and the estimated cost per km of tunneling is $70 million. Based on the expected number of stations for Asunción (14), and the expected length of 21.25 km, the cost of the whole system amounts to $2.1 billion.

4.2. Horizontal alignment

The horizontal alignment chose runs parallel to that of the BRT, a system currently under construction in Asunción. This alignment was chosen since, due to the BRT currently being built on the city, several studies have been done about it, including population flow and economic analyses which data we later used for our cost benefit analysis. Such alignment can be seen in Figure 4-2.

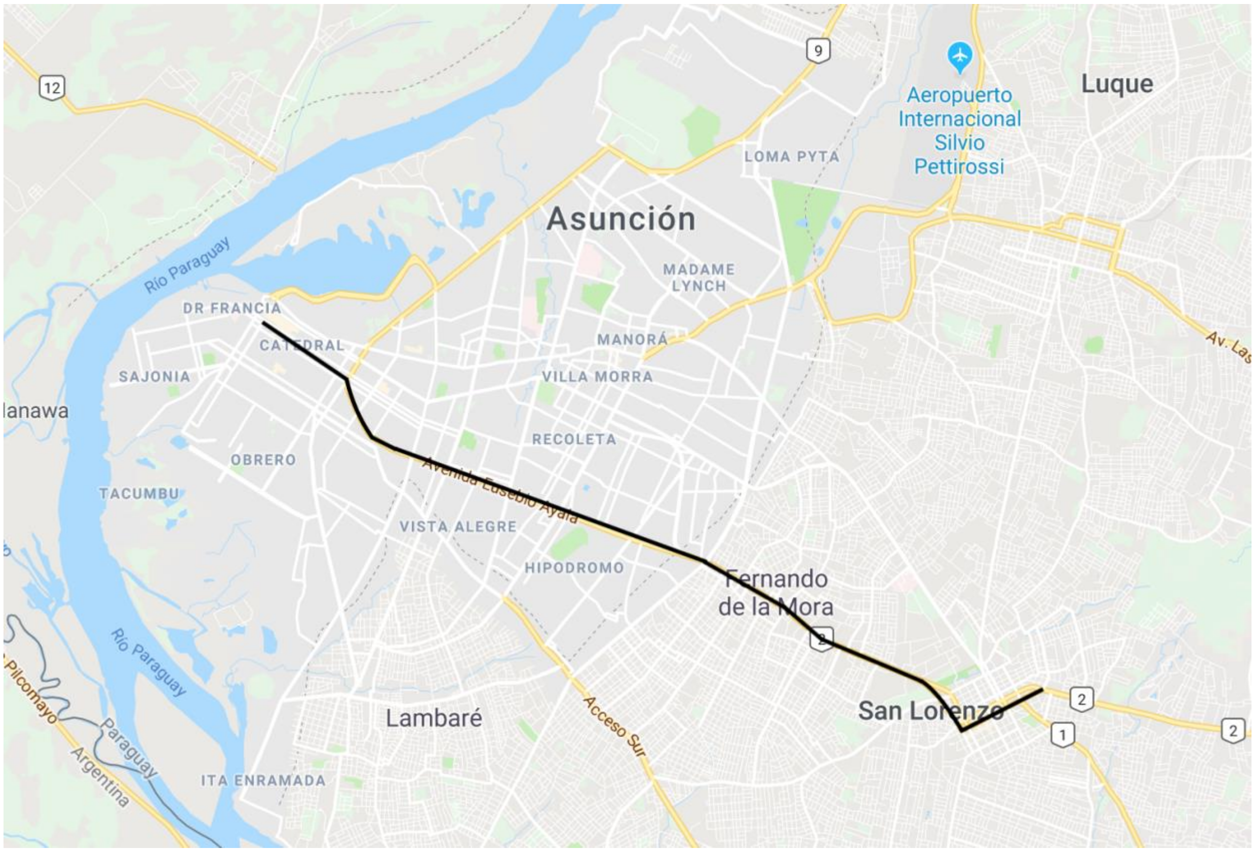

Figure 4-2. Metro alignment connecting the cities of Asunción and Luque

The endpoints of the system are in the "Centro" (the old city) of Asunción to the west, and Luque to the east. The alignment spans over 21.25 kilometers. The peak load is 14200 passengers per station and occurs at station 18 of the BRT. This number consists of all the passengers that are present in that station during a period of one hour. By passengers present in the system we refer to the passengers that come in the arriving buses to the station plus the ones that enter the system in that station minus the ones that exit the system on that station. Figure 4-3 shows this distribution, and it is important to note that this data was taken at the peak hours during the morning, and that it shows the number of passengers in the system at each station. Appendix A shows in more detail the information regarding the passenger flow between these endpoints during the morning peak hours, as well as the amount of passenger load for each section of the alignment. As it can be seen, the passenger load towards Asunción is much bigger than that towards San Lorenzo since most people work in Asunción. With this information, the average distance travelled per person per direction (assuming each person does two trips per day, to and from work) was determined to be 9.44 km. This number was determined using the following equation:

$$Average\ Distance\ Travelled = \frac{\sum(Distance\ between\ stations * Passenger\ load)}{\sum Boardings}$$

The expected annual ridership of the BRT system is expected to be 69 million per year (Logit, 2015), of which 10% are students (Logit, 2011). These students have a discounted fare of 50%, which was accounted for when performing the calculations for the revenue of the ticket sale.

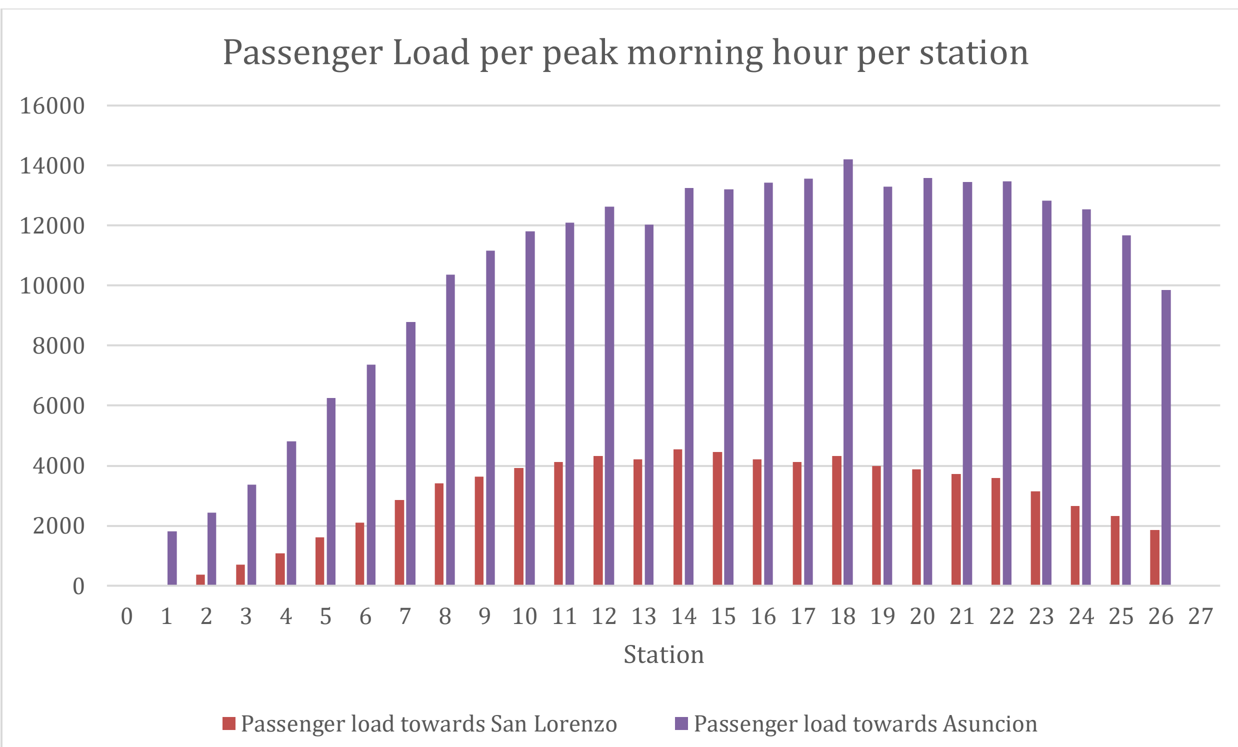

Figure 4-3. Passenger load per peak morning hour per station

4.3. Stations and train scheduling

The BRT system that is currently being built in Asunción has 28 stations planned for it, which can be seen in Figure 4-4. Their distribution, with coordinates on the map, and detail such as the distance between stations, can be seen in Appendix A. In average there is a distance of 0.78 km between them. Since we determined that the cost for each Metro station is $35 million, we decided to reduce the number of stations for our solution and placed them at the locations which have the highest flow of passengers (look at Appendix A), but also kept the distance between them reasonable. The result is shown in Figure 4-5, with a total of 14 stations, which average a distance of 1.63 km between them.

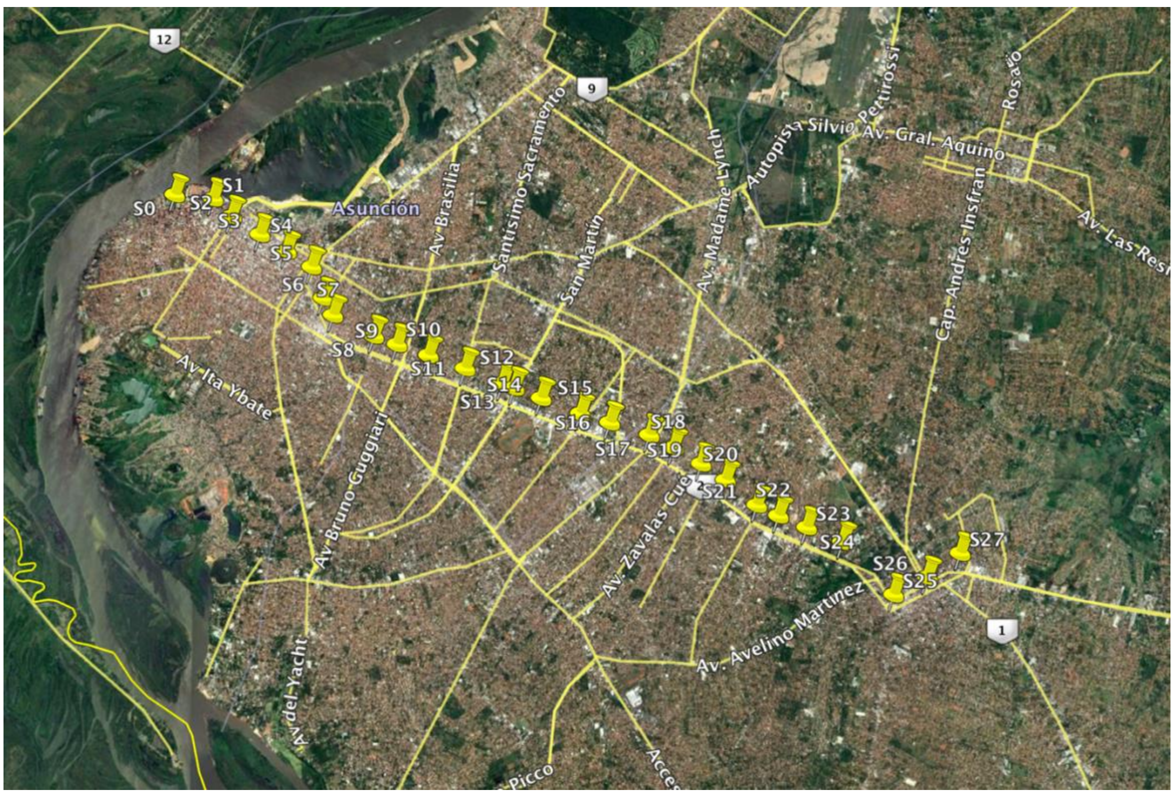

Figure 4-4. Stations for the BRT system

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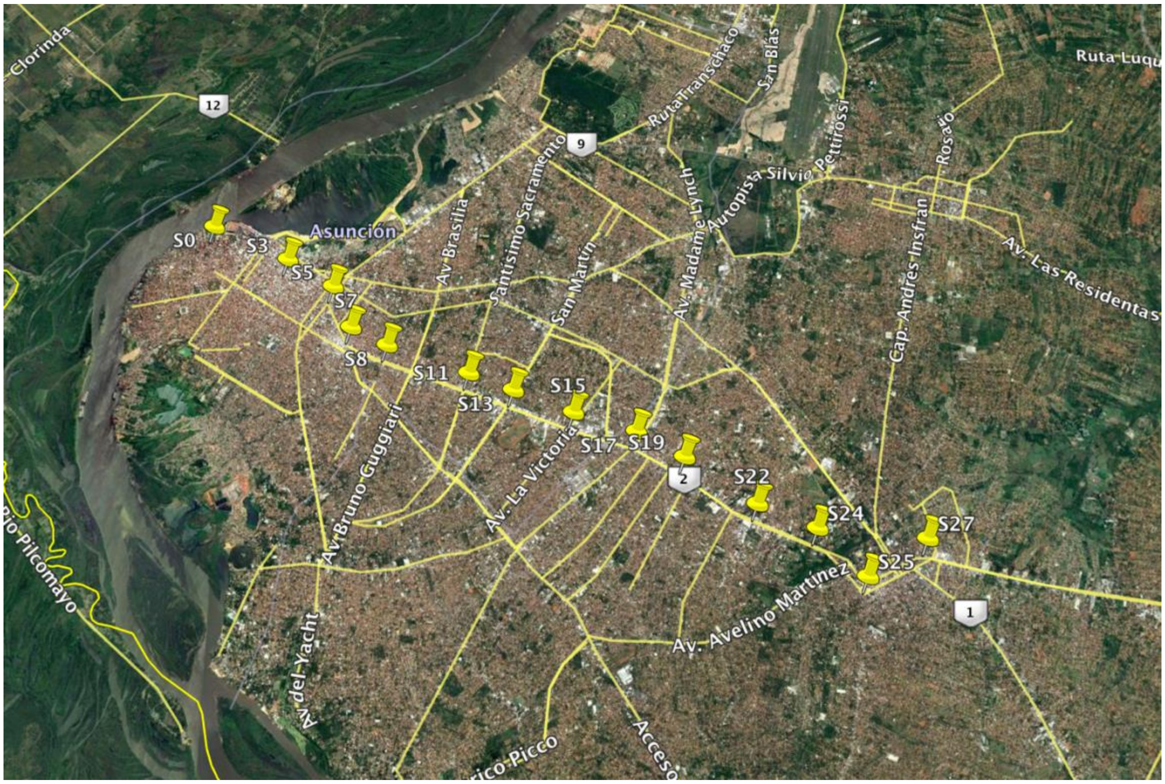

Figure 4-5. Stations for the proposed Metro system

In order to determine the train scheduling, we had to first determine the number of passengers that would be present during peak hours. This was taken from the study done for the BRT by Logit Consortium (2015), which was of 12537 passengers in the system per hour. The peak hours were considered to be from 6 a.m. to 9 a.m., and from 5 p.m. to 8 p.m. For the rest of the time periods, a reducing factor of 0.9 was applied to account for the difference in users during non-peak hours, and from 9 p.m. onwards the reducing factor was even lower, it being 0.5, 0.4, and 0.2 for the hours of 9 p.m., 10 p.m. and 11 p.m. respectively. As stated in the previous section, the capacity of each train is of 750 passengers. With that information, as well as the yearly peak hour users, we determined the number of trains required, which for the initial year were 17 trains (providing a capacity of 12750 passengers per hour).

In terms of the train scheduling, we consider that the trains are going to run at a speed of 50 km/h in average. The total length of the track is 21.25 km, and we consider that the trains stop at each station for 20 seconds, which translates to a total of 30.17 minutes to complete a one-way trip from the first to the last station. With this in mind and knowing that our fleet is composed of 15 trains, the frequency of incoming trains per station was determined to be 4 minutes. In the last year of our study, the demand will require 30 trains, which will improve the frequency to 2 minutes.

4.4. Tunneling

As explained earlier, the proposed system is modeled after the Beijing Metro lines. In order to save in tunneling costs, we decided to make one single tunnel which would accommodate the two tracks. This would need to be big enough to hold the two tracks, considering the dimensions of the trains themselves (3.27 m). For it, we chose a 10.22 m in diameter slurry type shield TBM, since it performs better on loose, water-bearing soft grounds such as the one present in Asunción. This is similar to the one used for the line 14 in Beijing (Li et al, 2004). The reason for choosing the TBM was to minimize disruption on the streets of the city. It needs a space of land to dig the shaft in which the TBM will later begin its excavation, but aside from that not much more. The depth at which this would be built is around 20 m, considering the diameter of the tunnel. Table 4-1 shows the technical data of the chosen machine, which is the same one used for the Line 14 of Beijing.

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Table 4-1. Characteristics of the selected TBM (Li et al, 2004)

Items	Parameters
Excavation diameter (mm)	10220
External diameter (mm)	10000
Internal diameter (mm)	9000
Segment thickness (mm)	500
Segment ring width (mm)	1800
Configuration of segments	9(8+1 keystone)
Machine length (mm)	11550
Cutter head rotation speed (r/min)	0-0.68
Advance rate (mm/min)	0-85
Total thrust (kN)	108000
Maximum torque coefficient (α)	α=32.2
Working torque (kN m)	22896-34344

The advance rate considered for the project is of 15 meters per day, which means the project will be completed in a little less than 4 years. Due to the characteristics of the soil, the excavation of the tunnel must be done sequentially with short advance lengths, and a rigid support of sprayed concrete must be provided as soon as the machine passes through a section to avoid settlement and collapse of the walls.This machine inserts the sprayed concrete between the external and internal diameters, with two layers of welded wire mesh and lattice girder for the primary lining. This creates an impermeable lining of 500 mm in thickness. A cross section of the estimated tunnel can be seen in Figure 4-6.

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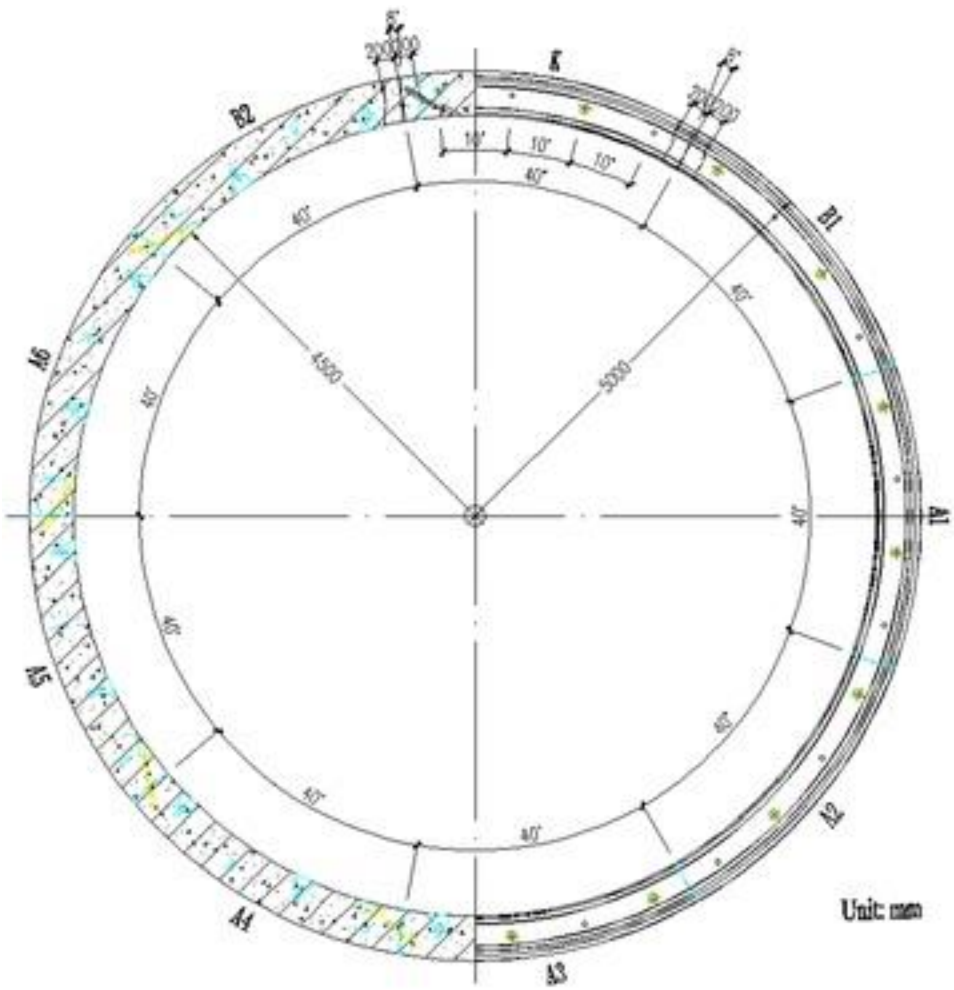

Figure 4-6. Cross section of tunnel (Li et al, 2004)

4.5. Train selection

We chose a Bombardier train to model our system. The information used was gathered from the latest contract this company had with the San Francisco Bay Area in 2012. This contract was signed for $639 million, for a total of 356 carts, which ends up being $1.8 million per cart (Lopez, 2017). We used this number for our cost calculations for the carts. These trains have a capacity of 170 persons (crush capacity is of 200 persons) per cart, as seen in Figure 4-7, and decided that they would be composed of 5 carts (2 motorcars and 3 intermediate trailer cars). We assumed this in order to prevent the stations from running too long. With each cart being

21.33 m long, this would make the length of the station to be 106.5 m. In addition to the length, each cart is 3.27 m wide and 3.27 m tall. The schematics of the Bombardier cart can be seen in Figure 4-8.

We assume, based on case studies, that the useful life of these trains is of 25 years. In our analysis, as can be seen in “Public Transportation” in Appendix B, we estimated the purchase of future carts based on the increasing population and starting from the year 2047 (the 25th year after the initial purchase), we can see a higher expenditure to account for the replacement of the units that have finished their cycle.

Contract awarded	June 2012
Operator	San Francisco Bay Area Rapid Transit District (BART)
Car length	21.33 m / 70’
Width	3.20 m / 10’ 6” (over side sheets) 3.27 m / 10’ 9” (over plugged passenger doors) 3.12 m / 10’ 3” (over thresholds)
Max. Speed	128 km/h / 80 mph
Passengers (seated and standing)	Average of 170
Train consist	From 3 to 10 cars

Figure 4-7. Technical data of the Bombardier trains for the San Francisco Bay Area (Retrieved from: https://www.bombardier.com/en/transportation/products-services/rail-vehicles/metros.html)

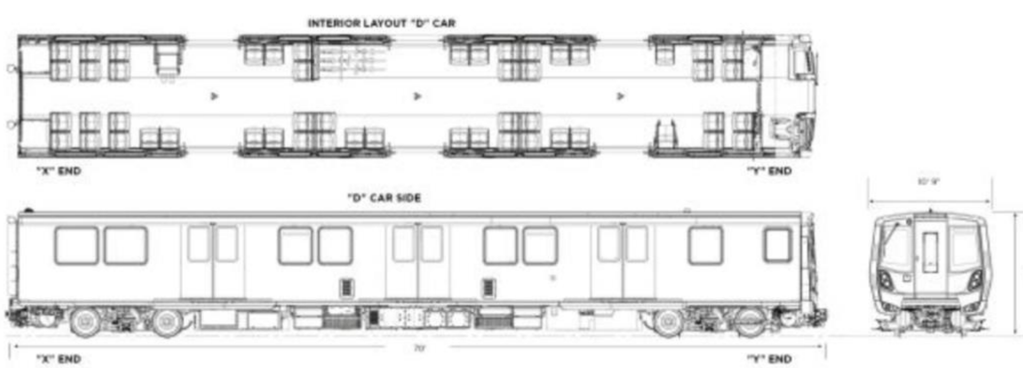

Figure 4-8. Technical drawing of Bombardier car for the San Francisco Bay Area (Retrieved from: https://www.bombardier.com/en/transportation/products-services/rail-vehicles/metros.html)

4.6. Summary of design paramters

The parameters discussed in this section are summarized in the following table:

Table 4-2. Summary of design parameters

Length of Metro (km)	21.25 km
Depth of Metro (m)	20 m
Number of stations	14
Cross section type	Single bore tunnel (which holds two tracks)
Diameter of tunnel (m)	10.22
Duration of construction (years)	4

4.7. Travel time and cost savings to the user

As stated earlier, this study is focused around the end users, and it aims to provide them with a faster and cheaper alternative to move around. Table 2-4. shows the time it takes to get along specific segments of major streets in Asunción, alongside with the average travel velocities, in directions towards and away from Asunción, at the peak hours of the morning, noon, and afternoon.

In order to compare these times with an estimated time for both the BRT that is currently under construction and the Metro, we took the coordinates of each of the stations of the BRT and placed them in Google Maps. From it, we took the distance between each of the stations, as well as the time it took to go from one station to the other, both ways, in a manner similar to the process for gathering the traffic on the main streets of the city.

Following this approach, we were able to get an estimate of the total travel time between each station, as well as the total travel time between station 0 ("Centro" of Asunción) and 27 (Luque) and vice versa. For the BRT system, we considered it would ran at a speed of 24 km/h (ABC Color, 2016), which is its predicted average speed, and the for the lightweight Metro system we estimated an average travel speed of 50 km/h from the Table 4-3. With this information we could get a preliminary estimate of the time it would take to move through the whole alignment by car or current buses (representing the current state Eusebio Ayala Avenue, the street where the BRT is being constructed), the BRT, and the underground Metro system. The comparison can be seen in Table 4-3., with a clear reduction of travel time, from an initial 82 minutes in car with current traffic, to 25 minutes on an underground system, reducing travel time by 70%. This translates to 41 hours in travel time reduction per month for the rider that goes through the whole line.

Table 4-3. Travel time comparison between car, BRT, and Metro underground system.

		To San Lorenzo	To Asunción
	Distance	21	21
Car (normal bus)	Total Time (min)	82	77
	Average speed (km/h)	19	22
BRT	Total time (min)	53	53
	Average speed (km/h)	24	24
Metro	Total time (min)	26	26
	Average speed (km/h)	50	50

The cost to move around using a Metro is also lower than using a personal vehicle. The cost per kilometer travelling by Metro is of $0.09, while that of the car is $0.85, making the difference almost reach a factor of 10. The cost of the car per kilometer was determined by dividing the annualized cost of the car (which is composed of the purchasing cost, the importation cost, taxes, insurance, parking, and maintenance cost such as lubricants and tires) by the expected number of kilometers driven in a year for commuting purposes. On the other hand, the cost per kilometer traveling on the proposed Metro system was determined by dividing the average distance per trip of 9.44 km by the cost of a ticket fare. The detailed calculations are explained in Appendix B, in the sections of "Public Transportation" and "Car Cost." Considering that the average worker has a five-day-work week, and that he commutes an average of 18.88 km roundtrip (the single trip is of 9.44 km and was explained in the previous section), he makes a total of 4,794 km a year, which translates to $4,550 by car or $433 by public transportation. We consider that a car typically lasts 11 years, in which time (and accounting for an inflation of 3.68%) this sums up to $60,850 by car and $5,800 by Metro, making the car ten times more expensive. In order to determine these values, we inflated the cost per kilometer for both the car and the metro to the expected number of years a car is expected to last (11 years) and multiplied that times the expected daily kilometers a commuter is expected to drive, times the number of working days in a year. This provided us the cost per year for each of the eleven years, which we later added. Bringing these values to the present using the 8% capitalization rate, the car trip costs amount to $38,110 and the public transportation trips to $3,600. The details can be seen in Table 4-4. On top of this economic savings, consider the 70% reduction in travel time.

Table 4-4. Car Cost vs Metro Cost

Year	Yearly Car Cost	Yearly Metro Cost
2018	$4,550.95	$433.11
2019	$4,718.43	$449.04
2020	$4,892.06	$465.57
2021	$5,072.09	$482.70
2022	$5,258.74	$500.47
2023	$5,452.27	$518.88
2024	$5,652.91	$537.98
2025	$5,860.94	$557.78
2026	$6,076.62	$578.30
2027	$6,300.24	$599.58
2028	$6,532.09	$621.65
Total	$60,367.33	$5,745.06
Net Present Value	$38,110.07	$3,626.87

Even though the savings from one system over the other are clear, not all the population currently using private vehicles is going to shift to public transportation. The Plan Ceta of

Asunción (1998) made an estimate that, without the implementation of the BRT, the expected number of cars in the city in 2015 was going to be of 1,355,442, and with the implementation of it would translate to 1,243,257. This happened over a span of 17 years, which means the yearly reducing factor was of 0.48% (the calculation can be seen in Appendix B under “Car Reduction”). We used this reducing factor to calculate all the savings that would arise from people shifting from one system to the other.

5. Cost Benefit Analysis

The successful implementation of a Metro system not only depends on the mechanical and operational aspect, but also on the financial aspect. It allows the engineers to know what resources are available and define how this project is going to be done. Many variables have to be taken into consideration when building a Metro, which are not only the cost of construction, but the sum of operational, overhaul, and maintenance costs. An economic analysis was done regarding the installation of a Metro line from the "Centro" of Asunción to San Lorenzo. It took into consideration the different types of costs building and operating a Metro implies and the benefits of its construction.

This cost benefit analysis was performed with the goal of identifying and quantifying the costs the Metro will represent in the next 50 years, the benefits to society, its economic return, and then determining a ratio between cost and benefit of this system. All the calculations and details can be seen in the Microsoft Excel file that accompanies this report: Asuncion_Metro_Cost_Benefit_Analysis, and its explanation can be found in Appendix B: Cost Benefit Analysis Excel Sheet Walkthrough. Figure 5-1 shows the main components of this analysis.

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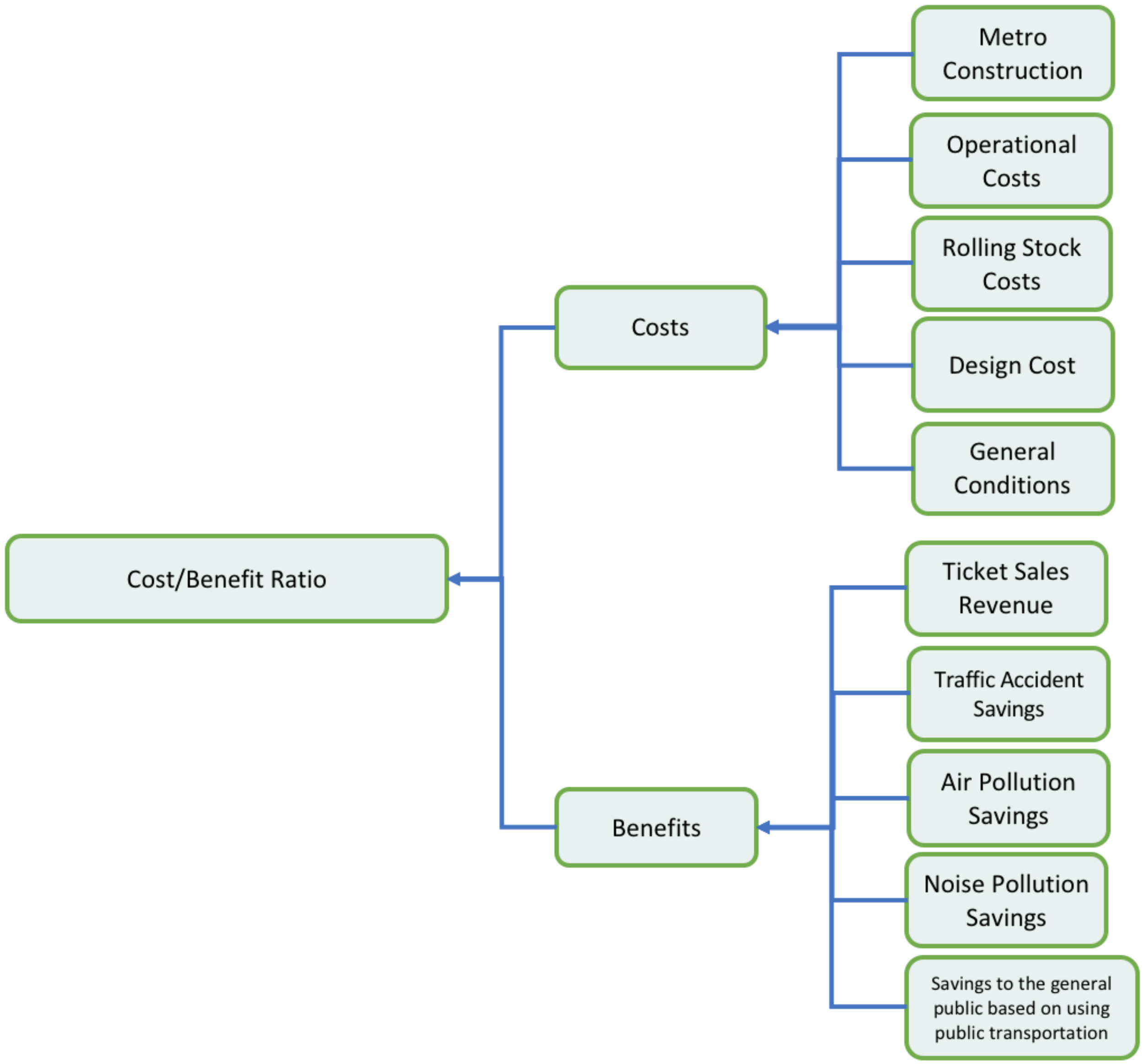

Figure 5-1. General components affecting the cost benefit ratio

5.1. Costs

The construction of a Metro system implies a large investment of funds to the entity responsible for its development. A Metro has all different kinds of costs; the team determined the main financial costs that the project would represent to properly incorporate this type of mass transportation system in the city of Asunción. There are essentially two types of major costs: capital investment to develop the system and operation and maintenance costs to make it run.

5.1.1. Metro Construction Costs

The team estimated the cost per kilometer that constructing a Metro system in Asunción would represent. The team based their numbers on different Metro lines built in other cities; mainly on the Metro line project of Beijing, China. The reason we chose this specific project was that Beijing has a very similar type of soil to Asunción's, which will be discussed further in Section 4.1. The cost per kilometer of the construction in Beijing was $82 million. Since the cost of constructing Metro stations in this type of project equals 30% of the total construction cost, and this project constructed 24 stations throughout their 28.2 kilometers of this Metro line, it would mean that they payed approximately $29 million per station and $57.5 million in tunneling. A minimum wage ratio, determined by dividing Paraguay's minimum wage by China's in dollars, was determined to extrapolate the costs in China to Paraguay. This ratio was equal to 1.22 (368 / 302.18) and was multiplied by the constructions costs previously mentioned. This would leave Paraguay's construction costs for a Metro line in approximately $93.3 million per kilometer. This Metro line would have 14 Metro stations, with a cost of $35.3 million per station, and 21.25 km of tunneling, at a cost of $70 million per kilometer excavated. This would leave the entire cost of the Metro line in $2 billion. Considering the total cost and the time it would take to construct, we transformed the present value to an annuity payed in a period of 4 years. We transformed this payment into an annuity by using a capitalization rate of 8%, which is the one used by the Paraguayan Government (Logit, Consorcio BRT Bus, 2016). The capitalization rate is the rate at which a property is expected to produce income (e.g. if property costs $10 and the income is $1, the capitalization rate is 10% (1/10)). To takes this payment into the future, we used an inflation rate of 3.68%, which was calculated by the average inflation rate of the last 5 years in Paraguay.

5.1.2. Operational Costs

The different costs listed in this section came from the "Revision Modelo Financiero 2015, BRT" paper. This paper presented a breakdown of the specific costs the BRT represents yearly. The annual cost of the BRT is approximately $6.8 million; the breakdown of these costs per category can be seen in Table 5-1.

Table 5-1.Breakdown of operational costs for BRT

Annual Operational Costs BRT	
Control center	$3,679,000.00
User information	$360,000.00
CCTV	$258,000.00
Employees	$1,350,000.00
Maintenance (infrastructure)	$161,398.00
Security posts contract	$716,700.00
Cleaning Contract	$249,000.00
Number of BRT stations	28
Total Cost in USD	$6,774,098.00

In Table 5-2, the breakdown of the total yearly operational costs of a Metro is shown. The control center, user information, CCTV, employees, maintenance, security posts contract, and cleaning contract costs are all based on the BRT costs. These costs were multiplied by 0.5 since the Metro system will have half than the BRT stations. In section 4.3 it is explained why the system has 14 stations instead of the 28 stations in the BRT system. Afterwards, these costs were multiplied by the "Metro/BRT operating cost ratio" of 1.91, which was determined by dividing the average operational costs of a Metro system by the average operational costs of a BRT system (MacKechnie, 2017). The energy consumption cost was calculated by using the energy consumption of a single cart in kWh (Sfeir, 2007), multiplied by the total number of carts (75), which were calculated based on the expected demand of the system, for the initial year of operation, and finally multiplied by the cost of electricity in Paraguay per kWh.

Table 5-2. Metro operational breakdown costs

Annual Operational Costs Metro	
Control center	$3,513,445.00
User information	$343,800.00
CCTV	$246,390.00
Employees	$1,289,250.00
Maintenance (infrastructure)	$154,135.09
Security posts contract	$684,448.50
Cleaning Contract	$237,795.00
Energy cost in Paraguay ($/kWh)	$0.04
Energy consumption per cart per year (kWh)	449108.6996
Number of carts	75
Total cost of energy consumption	$1,185,310.14
Number of metro stations	14
Adjusted Annual operating costs for metro	$7,654,573.73

5.1.3. Rolling Stock

The amount of rolling stock needed was determined based on the passenger volume, especially in peak hours. A regular cart can fit 170 people, and since the team decided to do smaller station to save on construction costs, we do not recommend trains larger than 5 wagons, which can accommodate 850 users total. Because of the demand, the system would require 15 trains of 5 carts each (total of 75 carts), with a frequency of 4 minutes. The life spam of the rolling stock is approximately 25 years, which would mean that the rolling stock needs to be changed after this time period. Another factor to take in consideration is the safety factor in case one train breaks down, which the team recommends to have an extra train in stock. Also, the system needs to increase the capacity based on the population increase, which would mean that a new train should be purchased every 3 to 4 years in average to satisfy the increasing demand of an increasing population.

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5.1.4. Design Cost and General Conditions

The design cost of a project of this magnitude englobes different types of costs: geotechnical and other soil tests, system layout design, construction type decision (e.g. type of construction (TBM or cut and cover)), and operating design (e.g. electric system design). According to The Office of Financial Management of The State of Washington, the design cost represents approximately 15% of the total cost of the project.

The general conditions are the part of the project that provides the legal framework and ensures that terms of the contract are fair for both parties. For example, this type of projects usually establishes certain conditions to ensure delivery times for construction, represented usually in financial fees in case the project is delivered after the date established.

5.2. Benefits

The proper implementation of a Metro system in a city can have a positive impact on the society and the country's economy, if properly implemented. The implementation of said system in the city of Asunción will bring economic benefits to the country and its people; not only will a project of this magnitude employ an enormous amount of people, but it will also create income for the institution in charge of it in the form of access tickets. Benefits are not only represented in the monetary side, they are also represented in environmental gains that have a positive repercussion on the population's health. The team determined that with the implementation of a Metro system in the city of Asunción, would improve the air quality and reduce noise pollution by reducing the number of vehicles in the streets.

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5.2.1. Ticket Sales Revenue

The ticket sale revenue depends in 2 main things: demand and cost. The expected demand, or passenger volume, a Metro system would have, is 190 thousand passengers per day ± 20 thousand passengers. This would mean an annual demand of 69 million passengers ± 7 million passengers. The cost of the tickets would be about $0.8, with a discounted fare for students which represent 11% of the expected users. This fare is an average rate that the user will pay based on the routes used by the average commuter; the information to determine this fare was extracted from "Logit, Consorcio BRT Bus 2016". Finally, this average fare rate would represent a revenue of $52.4 million ± $5.24 million, taking in consideration the reduced fare of students. The cost of the Metro ticket was determined by using the same fare the BRT system will use when it opens in 2019 (Logit, Consorcio BRT Bus, 2016).

The Metro line would have a discounted fare for its tickets, according to the different trips each commuter may have. Currently, the commuters have to pay the same fare for each of the bus trips they have to take to get to their desired location, this means that if the passenger has to take 3 busses, he has to pay the full cost of a bus trip 3 times. Our proposal would recommend the Metro system to have a discounted fare depending on the trip, like the BRT is going to be using (Table 5-3), this way users will not have to pay the base fare each time they switch vehicle. Obviously, this would have a time limit, so for example the user will not be charged the fool fare twice if he uses two feeding lines within an hour, but if it is after a certain time frame, they will have to pay the fare for each trip.

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Table 5-3. Fare for different trip types.

Different Trip Types	**Trip Fare**
1 or more main lines	Trip type 1 ($0.612)
1 feeding line	Trip type 1 ($0.648)
1 main line and 1 or more feeding lines	Trip type 2 ($0.648)
2 feeding lines	Trip type 2 ($0.648)
2 feeding lines and 1 or more main lines	Trip type 2 ($0.648)
3 feeding lines	Trip type 3 ($1.26)
3 feeding lines and 1 or more main lines	Trip type 3 ($1.26)

5.2.2. Traffic Accidents Savings

A traffic accident is defined as an event on the road, such as a car collision, which involves death or injury of people, and/or property damage (Másilková, 2017). They cause damage to property, health, and life, moreover they also incur an enormous cost on the governments. In the year 2017, the Paraguayan government payed an approximate of $209 million due to traffic accidents. The cost of these accidents includes cost of traffic disruption, amount that the people stop earning and spending, and medical expenses. As seen in the Table X in Appendix X, the Government of Paraguay is expected to pay $50.5 billion due to traffic accidents in the next 50 years. According to Plan Ceta (1998), the implementation of a mass transportation means in Asunción would reduce the amount of personal transportation in the streets by 0.49%. Assuming that the reduction of cars is linear with the reduction of accidents, the Government of Paraguay would save an estimate of about $246 million in the next 50 years. Although, if we bring this number to the present, with an 8% capitalization rate, this number would be equivalent to $24 million.

5.2.3. Air Pollution Savings

Asunción's air pollution originates mainly from the enormous number of vehicles in the city, which emit pollutant chemical elements into the environment. The cost of air pollution mainly originates from the health an environmental impact these chemical compounds have. Assuming an even distribution of cars amongst the Paraguayan population, Asunción would possess about 340,000 cars in 2017. This is because 32% of the country's population lives in Asunción, and Paraguay had an estimate of 1,060,000 cars. The average cost per kilometer because of air pollution a car owner represents is between $0.03 and $0.06 per kilometer, in 1997, this would then be multiplied by the distance an average commuter travels yearly (± 5 thousand kilometers) to determine the air pollution cost per car. These costs were then taken to the future using the average inflation of the country and would represent a cost between $0.63 and $1.21 per kilometer. Using the average cost of air pollution, the cost of an average car owner commuter in Asunción has is roughly $70 per year; when multiplying this by the number of cars and taken them to the futures, air pollution would represent an estimated cost of $19.8 billion, in the next 50 years. The costs shown above originate from the

Assuming that the construction of the Metro would reduce the number of cars by 0.49%, the government would save an estimate of $42 million, over the course of 50 years, because of the reduction of car emissions in the environment. This savings brought to the present, using a capitalization rate of 8%, would represent savings of $14.24 million.

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5.2.4. Noise Pollution Savings

According to Zegras (1997), the noise pollution costs are mainly attributed at the health problems which are the result of exposure to high noise levels. Hearing loss is the main problem and can result in many hours of work lost because of this.

The same assumptions used in the "Air Pollution Savings" sections were made to determine the number of cars and motorcycles in Asunción; the result was approximately 340,000 cars and 176,000 motorcycles in 2017. The total cost incurred because of noise pollution in the next 50 years is expected to be $4.15 billion. These costs were calculated using the costs in 1997 of noise pollution, which were $0.001 per kilometer for a car and $0.007 per kilometer for a motorcycle. This taken to the future, using the average inflation in Paraguay is 0.0028 and $0.014 respectively.

The reducing factor of vehicles, as said in the previous section, is 0.49%, which would represent 1$4.5 million. This number brought to the present using an 8% capitalization rate, would give us a $2 million saving.

5.2.5. Savings to Users

There are many different costs owning a car represents, like for example: insurance, technical inspections, fuel cost, parking cost, buying the car itself, among others; they all add up to a cost of $0.93 per kilometer. Using the Metro is cheaper, with a cost of $0.09 per kilometer. The average time an average Paraguayan has a car is 11 years, with an average commute of 18.44 kilometers, and an average of 260 working days per year. Under these circumstances, the total cost of owning a car for the average Paraguayan is $60.4 thousand, with a net present value of $56 thousand using an 8% capitalization rate. While under this same scenario, the cost of using the Metro for commuting would be $5.8 thousand, with a net present value of $5.4 thousand, reducing the cost significantly.

The use of the Metro, with our 0.49% reducing factor, would represent a total of $2.3 billion saved along 50 years for the Paraguayan people, with a net present value of $224 million using the 8% capitalization rate.

5.3. Sensitivity Analysis

In order to assess the economic analysis, and since it was done based on data gathered from other studies, as well on some assumptions, we performed a sensitivity analysis. There were some variables that presented some variability, and the change in these could sometimes have a substantial impact on the final cost benefit ratio. Such variables were: the cost of Metro construction per kilometer, the inflation rate, the energy cost, the number of carts, e ticket fare, the public annual demand, the air pollution cost per kilometer, the noise pollution cost per kilometer both from cars and motorcycles, the excavation rate, and lastly the car reduction factor. All of these values were calculated for each of the fifty years, when they happened, and then discounted to the present through the discount cash flow method. The following sections explain the criteria taken to establish the range for each of the factors, and the impact a unit change to each of this has on the general result.

5.3.1. Cost of Metro construction

The cost of Metro construction per kilometer has a direct impact on the cost benefit ratio since it is one of the largest costs of the projects. We based the cost for this project on the Beijing Metro Line 4, as explained earlier, due to the similarities in the soil of that city as well as the similar labor cost. However, this cost is subject to a big change. We look into the costs of several other projects, which can be seen in Table 5-4.. As it can be noted, the costs are very fluctuant from one place to the other, the US presenting the highest costs in the market. This are impacted by things such as type of soil, the labor cost, the strength of unions which require a lot of capital investments to be satisfied, among others. For our own study, we focused on the ones that had a soil type closest to that of Asunción, such as Barcelona. We centered our attention on the least costly ones, since labor cost in Paraguay as well as construction materials tend to be low. For this, we considered the minimum subway construction cost per kilometer to be $40 million, and the maximum to be $170 million.

As it can be seen in Figure 5-2, when considering the minimum cost of $40 million per kilometer, the cost benefit ratio is largely reduced to 1.16, 50% of its original value, and making the costs almost smaller than the benefits. This results in a total present value of construction costs of $895 million. On the other side, if we consider the cost to be of $170 million per kilometer, it makes the cost benefit ratio increase by 172%, reaching 4.00. This translates to a present total construction cost of $4.9 billion.

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Table 5-4. Cost of various underground subway projects (Nunns, 2016)

Location	City (Country)	Length (km)	Cost (2010 $)
East Side Access	New York (US)	2	$4,000,000,000
Second Avenue Subway Phase 1	NY (US)	3	$1,700,000,000
Crossrail	London (GB)	22	$1,000,000,000
Central Subway	SF (US)	2.7	$500,000,000
Singapore Downtown MRT Line	Singapore (SG)	42	$490,000,000
Amsterdam N-S Line	Amsterdam (NL)	9.5	$410,000,000
City Rail Link	Auckland (NZ)	3.4	$410,000,000
Budapest Metro Line 4	Budapest (HU)	7.4	$360,000,000
Toei Oedo Line 4	Tokyo (JP)	40.7	$350,000,000
Nanakuma Line Extension	Fukuoka (JP)	1.4	$320,000,000
Paris Metro Line 14	Paris (FR)	9	$230,000,000
Copenhagen Circle Line	Copenhagen (DK)	15.5	$170,000,000
Barcelona L9/L10	Barcelona (ES)	47.8	$170,000,000
Naples Metro Line 6	Naples (IT)	5	$130,000,000
Milan Metro Line 5	Milan (IT)	5.6	$110,000,000
Seoul Sin-Bundang Line	Seoul (KR)	18	$90,000,000
Helsinki WestMetro	Helsinki (FI)	13.5	$70,000,000
Seoul Subway Line 9	Seoul (KR)	27	$40,000,000
BarcelonaSants-La Sagrera Tunnel	Barcelona (ES)	5.8	$40,000,000

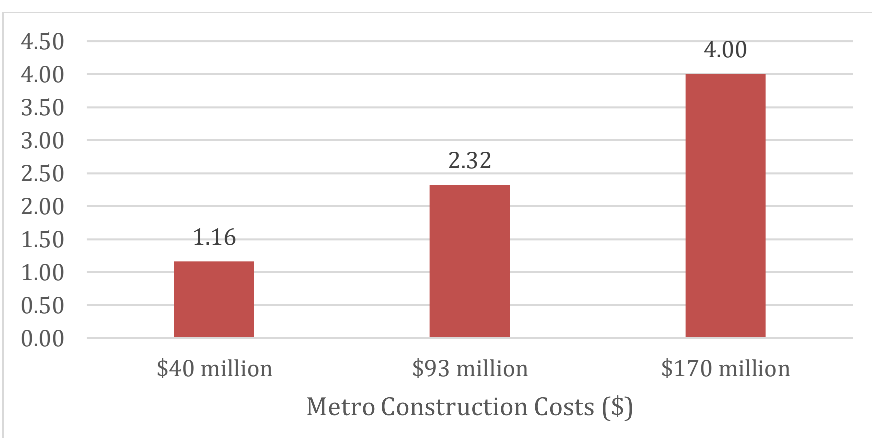

Figure 5-2. Impact of Metro construction cost on cost benefit ratio

We also considered the impact on the cost benefit ratio based on a unit change. Whenever the cost per kilometer was increased or decreased by $1 million, the cost benefit ratio presented change of 0.2, meaning a change of 0.9%.

5.3.2. Inflation rate

The inflation rate is a value that has a big impact in the construction of the Metro itself, since it establishes how present costs will behave in the future. Table 5-5. shows the inflation rates of Paraguay for the last 20 years. These inflation rates average 6.81%. However, this number is not representative since Paraguay went through a financial crisis during the last years of the 1990s and risked going into default in 2003. Ever since the economy has been improving (with the exception of the global financial crisis of 2008). In view of this, we considered two different alternatives: an inflation rate that represented the last 5 years, from 2013 to 2017, since this would account for the good present Paraguay has been enjoying. We also considered an 8-year span, going to 2010, to account for bad years as well. Paraguay, along with the world, was recovering from the financial crisis in that time. This 8-year timeframe had an average inflation rate of 4.39%.

We considered that the inflation rate would oscillate between 3.68% and 4.39%. The higher the inflation rate, the better it is for the cost benefit ratio, since a big percentage of the costs occur during the first years, while the benefits prolong through time. The 3.68%, which is the percentage we used for our base case, yielded a cost benefit ratio of 2.32. On the other hand, the 4.39% inflation rate translates to a cost benefit ratio of 2.12. This represents a reduction of 8.62%. A change of 1% in the inflation rate translates to a change of 0.09 in the cost benefit ratio, a variation of 3.9%.

Table 5-5. Inflation rates in Paraguay from 1997 to 2017

Year	Inflation
1997	7%
1998	11.6%
1999	6.8%
2000	9%
2001	7.3%
2002	10.5%
2003	14.2%
2004	4.3%
2005	6.8%
2006	9.6%
2007	8.1%
2008	10.2%
2009	2.6%
2010	4.7%
2011	8.3%
2012	3.7%
2013	2.7%
2014	5%
2015	3.1%
2016	4.1%
2017	3.5%

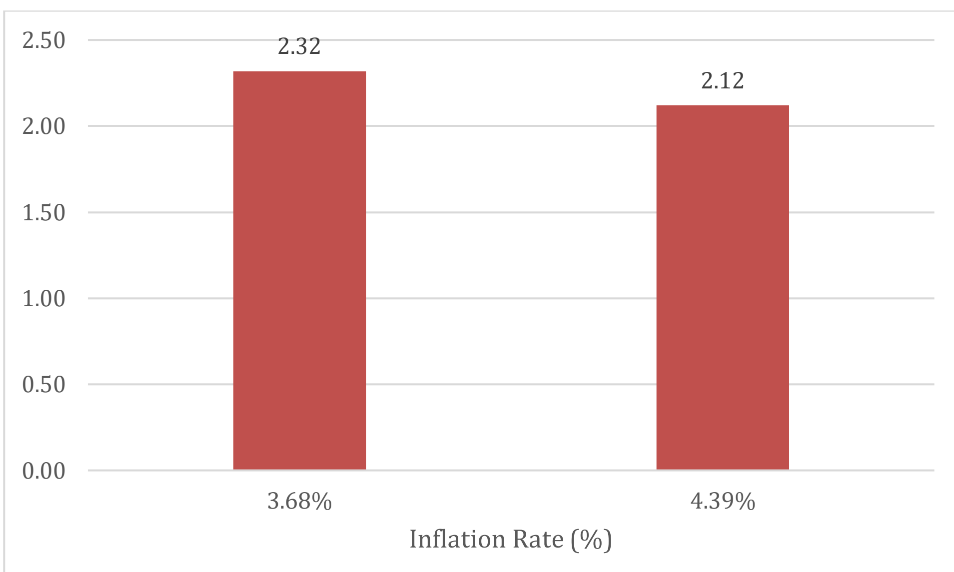

Figure 5-3. Impact of inflation rate on cost benefit ratio

5.3.3. Electric Energy Cost

According to the National Electricity Administration (ANDE) of Paraguay, the electricity fare is of $35.19 per MWh. Each of the carts we are using for our study consumes 449,108 kWh per year (Sfeir, 2007). A study done for the BRT (Logit, 2015) performed a sensitivity analysis as well, and when analyzing the electricity costs, considered a shift of 50% in the fare. We did the same for our study. The base cost was of $0.035 per kWh, with the minimum being $0.018 per kWh (50% of the original cost), and the maximums cost being $0.053 per kWh (a 50% increase). Table 5-6. shows the impact of this change in the cost benefit ratio, and as can be observed, it is minimum. In terms of significant figures, the reduced 50% energy fare had no impact on the cost benefit ratio, while the increase to $0.053 per kWh changed the cost benefit ratio by 0.01, a change of 0.43%.

Table 5-6. Impact of electric energy cost on cost benefit ratio

Energy Costs		Cost Benefit Ratio	Variation
Minimum	$0.02	2.32	0.00%
Current	$0.04	2.32	0.00%
Maximum	$0.05	2.33	0.43%

5.3.4. Number of Rolling Stock

The number of rolling stock will change as time goes on. We based the calculations for the quantity of rolling stock based on the user demand at the peak hours. For the initial year of operation (2022), there was the need for 75 carts, plus the extra 5 we consider as a safety factor in case some of them break down. By the last year of our analysis, there is the need of 155 rolling stock. Each of this rolling stock is worth $1.8 million (Lopez, 2017). The change in the cost benefit ratio however, is not a big one based on the change of rolling stock. From the first year of activity of the Metro, in which there is a requirement of 75 rolling stock, to the year

2068, where there are 155 rolling stock, the change was a mere 0.86% in the cost benefit ratio, taking it from 2.32 to 2.34, as can be seen in Table 5-7..

Table 5-7. Impact of number of rolling stock on cost benefit ratio

Number of carts		Cost Benefit Ratio	Variation
Minimum	75.00	2.32	0.00%
Maximum	155.00	2.34	0.86%

5.3.5. Ticket Fare

The model we created allows to change the fare for the tickets and evaluate the impact it has on the cost benefit ratio. The minimum value considered was 4464 Guaranis ($0.80), the same one used for the BRT, as explained in section 5.2.1. We allowed the cost of the fare to go as high as 5500 Guaranis ($1), an increase of 20%.

It is important to note that a change in the fare, especially if we actually change it by 20%, the demand is also going to change. A simulation study should be done to evaluate the behavior of the demand based on the changes made to the ticket fare. However, since we are performing a sensitivity analysis to evaluate the impact on the cost benefit ratio due to a change in the fare, we considered that the demand remains the same. As can be seen in Figure 5-4, the change from $0.80 to $1, with the demand remaining unaffected by this, alters the cost benefit ratio by 0.35, a shift of 15%. Thus, a unit change of 1000 Guaranis changes the cost benefit ratio by 0.34, making it the value with the largest impact.

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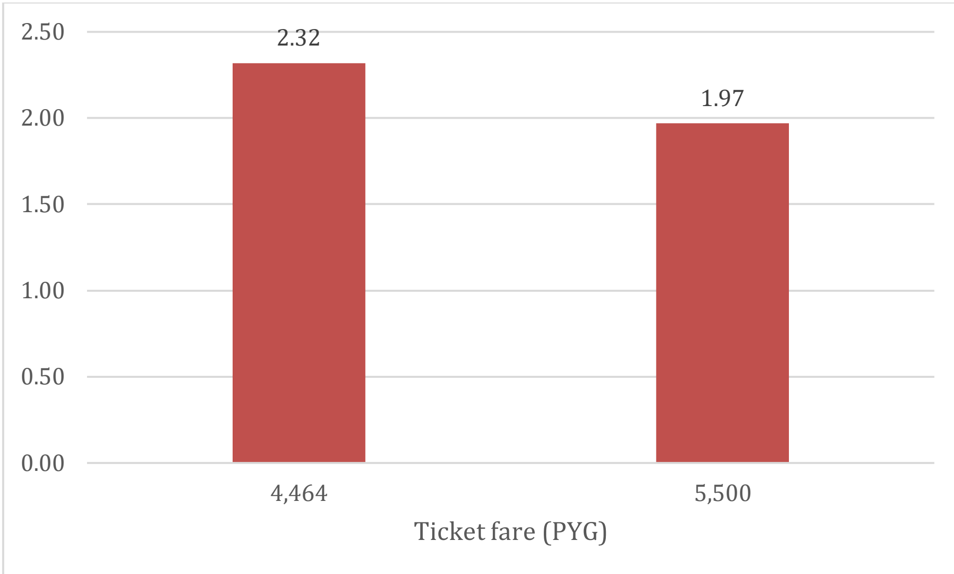

Figure 5-4. Impact of the ticket fare on the cost benefit ratio

5.3.6. Fuel Cost

The change in the cost of the fuel has a direct impact on the benefits since it affects the savings of the users who will stop using private transportation in favor of the Metro. The base cost of fuel for this study was assumed to be $0.83 per liter. According to the World Bank and as can be seen in Figure 5-5, the cost of fuel has shifted a lot in the last 17 years, constantly increasing until 2012, while now being in a declining trend. For this, we considered a possible variation of the fuel cost by 50%.

The sensitivity analysis thus, considers a minimum fuel cost of $0.42 per liter and a maximum of $1.25. With the cost of $0.42, the cost benefit ratio jumps to 2.35, and with $1.25 it is reduced to 2.30, as can be seen in Figure 5-6. This is a variation of 1% in the cost benefit ratio. We considered a unit change of 10c in the cost to evaluate the change in the cost benefit ratio per unit change of the variable, however it did not produce any change.

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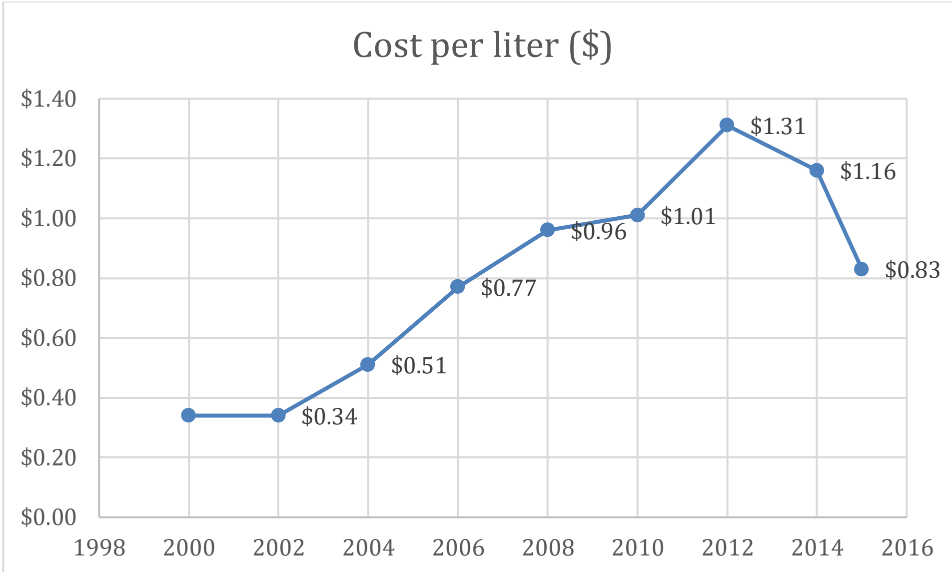

Figure 5-5. Cost per liter of fuel ($)

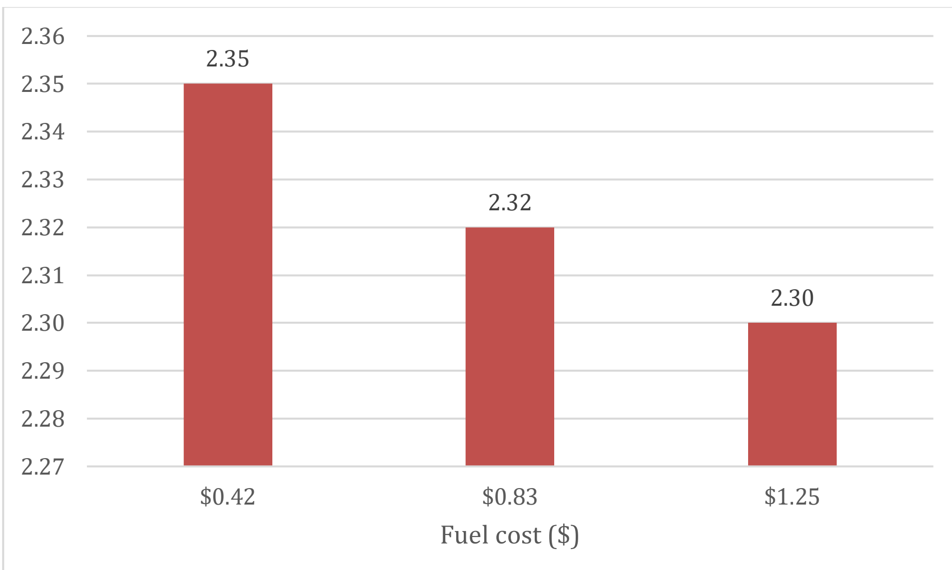

Figure 5-6. Impact of the fuel cost on the cost benefit ratio

5.3.7. Public Annual Demand

The model also allows for a change in the user demand of the system. The base model considers an annual ridership of 69 million, as was stated in 5.2.1. In studies done for the BRT system, a shift of 10% was applied to the demand to evaluate how it impacted their own economic analysis. We are going to do the same here, with a minimum demand of 62 million passengers and a maximum demand of 76 million.

The public annual demand is affected by the ticket fare, as was stated in 5.3.5, however, since we are evaluating the impact of this single variable on the demand, we do not account for it. The lower limit of 62 million passengers had an impact of 8.62% on the cost benefit ratio, making it 2.52. On the other hand, the upper limit of 76 million passengers reduced the cost benefit ratio by 6.9%, making it 2.16. A change of 1 million passengers in these variables has an impact of 0.2 in the sensitivity analysis.

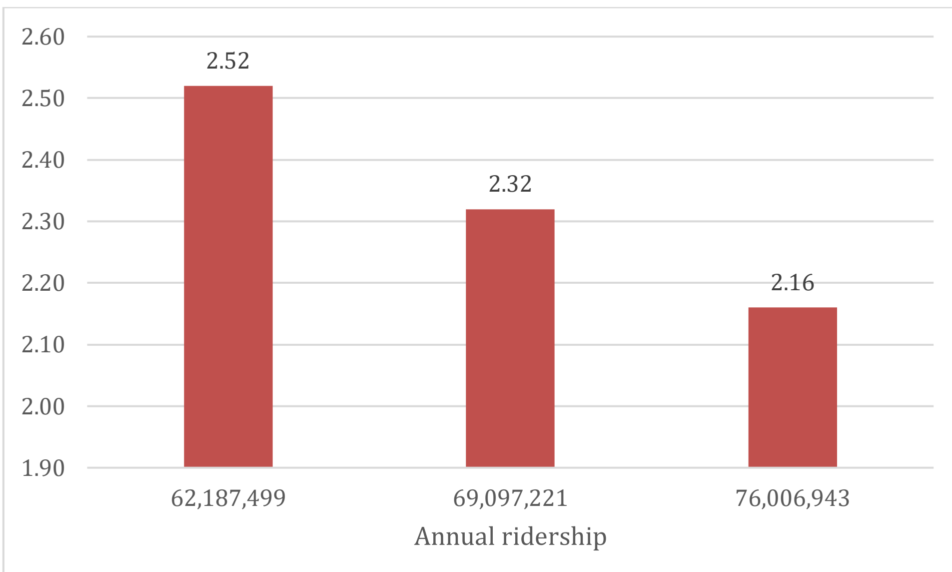

Figure 5-7. Impact of annual ridership on cost benefit ratio

5.3.8. Air Pollution Cost

The air pollution costs also present some variability. As it was explained in 5.2.3, the base value used for this study was a cost of $0.05 per kilometer travelled. This came from a low estimate and a high estimate of the costs per kilometer, based on the impact cars have on air pollution. Such limits were $0.03, and $0.06 (Zegras, 1997). However, a change in these parameters had no effect on the cost benefit ratio, as can be seen in Table 5-8.. When considering the minimum cost of $0.03, the ratio varied by 0.43%, which is negligible.

Table 5-8. Impact of air pollution cost in the cost benefit ratio

Air pollution costs ($/km)		**Cost Benefit Ratio**	**Variation**
Minimum	0.034	2.33	0.43%
Current	0.049	2.32	0.00%
Maximum	0.064	2.32	0.00%

5.3.9. Noise Pollution Cost

The noise pollution costs arise from both the cars and motorcycles. The motorcycles have a high-pitched motor, which leads to larger costs than that of the cars. The base cost for cars was $0.003, while the one for motorcycles was $0.014, almost 5 times more. In terms of the limits, we considered a variation of 50% for each of them, with the limits for the car noise pollution being $0.001 and $0.004, and the ones for the motorcycle being $0.007 and $0.021. The variation of these parameters however, had little impact on the cost benefit ratio. The lower limit presented a variation of 0.43%, which, similar to the previous section, is negligible. This can be seen in Table 5-9. and Table 5-10..

Table 5-9. Impact of car noise pollution cost on cost benefit ratio

Noise pollution costs of cars ($/km)		**Cost Benefit Ratio**	**Variation**
Minimum	0.001	2.33	0.43%
Current	0.003	2.32	0.00%
Maximum	0.004	2.32	0.00%

Table 5-10. Impact of motorcycle noise pollution cost on cost benefit ratio

Noise pollution costs of motorcycle ($/km)		**Cost Benefit Ratio**	**Variation**
Minimum	0.007	2.33	0.43%
Current	0.014	2.32	0.00%
Maximum	0.021	2.32	0.00%

5.3.10. Excavation rate

The excavation rate affects the construction cost directly since, the longer it takes to excavates the tunnels, the longer the costs prolong into the future, which increases the total cost of the work due to inflation. We made the model such that the number of years to build the project depended on this factor and chose a base excavation rate of 15 meters per day. As can be recalled from 2.2.6, the advance rate for clayey soils was slow, reaching speeds as low as 9 meters per day. The maximum speed that can be reached is of 30 meters per day, however, due to the type of soil, it is unlikely that this rate will be reached.

Figure 5-8 shows how these values impact the cost benefit ratio. When decreasing the excavation rate to 9 meters per day, the construction time increases from 4 to 7 years, increasing the cost benefit ratio by 5% to 2.43. On the other hand, when increasing the excavation rate to 30 meters per day, the construction time is cut in half to 2 years, decreasing the cost benefit ratio by 3% to 2.26. When considering a unit change, we determined it to be of 5 meters per day, since this change is the equivalent to shift of one year of construction. This unit change had an impact of 1% on the cost benefit ratio.

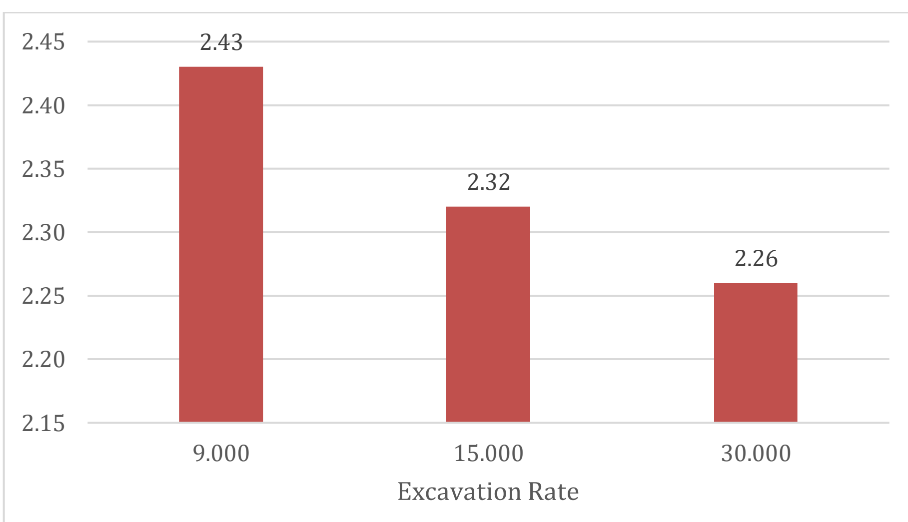

Figure 5-8. Impact of the excavation rate on the cost benefit ratio

5.3.11. Reduction Factor

As explained earlier, the reduction factor indicates the shift of the population from using private transportation to using public transportation after the implementation of the Metro. This reduction factor was taken from a prediction done in Plan Ceta (1998), which estimated the number of cars in 2015 with and without the implementation of the BRT system. From it, we got that the reduction factor was 0.49%. This translates into immediate savings to the users, since as it was explained in 5.2.5, it is about 10 times cheaper to travel in the Metro as opposed to the bus. The calculations can be seen in the "Car Reduction Factor" tab in Appendix B.

In order to analyze the variation of the cost benefit ratio as the car reduction factor changed, we considered a shift of 50% for the lower limit, setting it at 0.24%, and an increase of 100% for the upper limit, which would take it to almost 1%. As it can be seen in Figure 5-9, the impact on the cost benefit ratio is quite significant. The lower limit makes the cost benefit ratio 2.60 (12% increase), and the upper limit reduces it to 1.91 (18% decrease). As it can be seen, this variable, along with the ticket fare, are the ones with the most impact on the economic analysis. The more people that shift to the new public transportation system, the more benefits is going to generate for them.

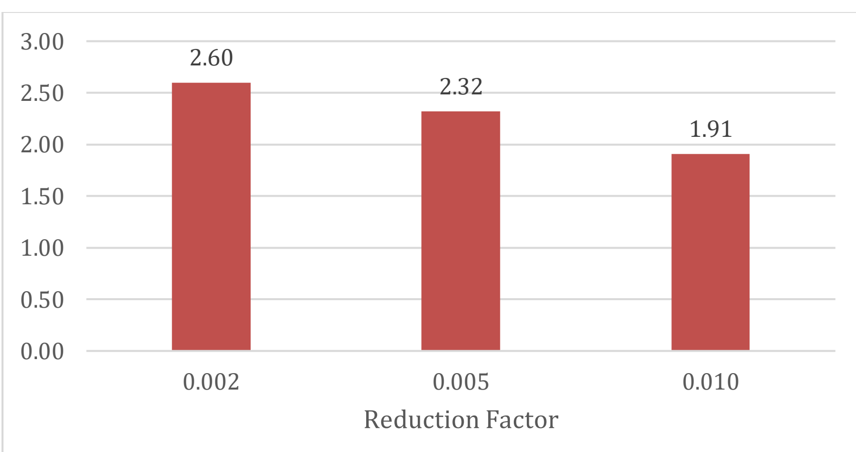

Figure 5-9. Impact of the reduction factor on the cost benefit ratio

5.3.12. Best and worst-case scenarios

To conclude our analysis, we considered three scenarios: the base one that has been discussed throughout this document, as well as a best and worst-case scenario. As it was discussed in the previous sections, some variables affected the cost benefit ratio positively when being at their upper limit, and some when being at their lower limit. Table 5-11. presents a comparison between the different scenarios. The light orange highlight means the variable's upper limit presents the worst-case scenario, while the green one means the lower limit results in the worst-case scenario. These limits can be seen in Table 5-12.

Table 5-11. Comparison between worst, base, and best-case scenarios

Parameters	Worst case scenario	Base scenario	Best case scenario
Metro Construction Cost per km	$170,000,000.	$93,285,614	$40,000,000
Inflation rate	3.68%	3.68%	4.39%
Energy Cost ($/kWh)	$0.05	$0.04	$0.02
Number of carts	155	75	75
Ticket fare (PYG)	Gs. 4,464	Gs. 4,464	Gs. 5,500
Fuel Cost ($/L)	$0.42	$0.83	$1.25
Public annual demand	62187499	69097221	76006943
Air Pollution Cost per Km ($/km)	$0.03	$0.05	$0.06
Noise Pollution Cost Car per Km ($/km)	$0.00144	$0.00288	$0.00433
Noise Pollution Cost Motorcycle per Km ($/km)	$0.00711	$0.01422	$0.02132
Excavation Rate (m/day)	9	15	30
Reduction factor	0.002434305	0.004868609	0.009737219
Cost benefit ratio	5.23	2.32	0.68

As it can be seen, the worst-case scenario yields a cost benefit ratio of 5.23, more than twice the original case. On the other hand, the best-case scenario yields a cost benefit ratio of only 0.68, making the costs lower than that of the benefits.

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Table 5-12. Minimum and maximum limits for the parameters

Parameters	Minimum	Medium	Maximum	Current
Metro Construction Cost per km	$40,000,000	$93,285,614	$170,000,000	$93,285,614
Inflation rate	3.68%		4.39%	3.68%
Energy Cost ($/kWh)	$0.018	$0.035	$0.053	$0.035
Number of carts	75	90	155	75
Ticket fare (PYG)	Gs. 4,464		Gs. 5,500	Gs. 4,464
Fuel Cost ($/L)	$0.42	$0.83	$1.25	$0.83
Public annual demand	62187499	69097221	76006943	69097221
Air Pollution Cost per Km ($/km)	$0.03	$0.05	$0.06	$0.05
Noise Pollution Cost Car per Km ($/km)	$0.0014	$0.0028	$0.0043	$0.0028
Noise Pollution Cost Motorcycle per Km ($/km)	$0.0071	$0.0142	$0.0213	$0.0142
Excavation Rate (m/day)	9	15	30	15
Reduction factor	0.24%	0.49%	0.97%	0.49%

Table 5-13 displays the actual shift in the different costs and benefits for the different cases. As can be seen, the worst-case scenario has a total cost of $5 billion. On the other hand, the best-case scenario is much lower, reaching $1.4 billion with benefits going up to $2 billion. The costs and benefits are spread over the years of the study, which is from 2018 to 2068, and then brought to the present using discounted cash flow analysis.

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Table 5-13. Cost and benefits of the worst, base, and best-case scenarios

	Parameters	Worst case scenario	Base scenario	Best case scenario
Costs	Metro construction ($)	$3,992,153,660	$2,087,189,866	$867,929,687
	Operational costs ($)	$170,155,398	$128,401,256	$136,136,168
	Rolling stock cost ($)	$222,498,604	$222,498,604	$222,498,604
	Design cost (15%)	$598,823,049	$313,078,480	$130,189,453
	General Conditions (5%)	$199,607,683	$104,359,493	$43,396,484
	Total	$5,183,238,395	$2,855,527,701	$1,400,150,397
Benefits	Ticket sales revenue ($)	$867,778,659	$964,198,510	$1,484,469,141
	Traffic Accident Savings ($)	$11,993,632	$23,987,265	$56,383,471
	Air pollution savings ($)	$4,896,602	$14,244,662	$43,976,407
	Noise Pollution savings ($)	$492,289	$1,969,158	$6,925,743
	Savings to users ($)	$105,650,156	$224,050,147	$462,039,585
	Total	$990,811,341	$1,228,449,745	$2,053,794,350

6. Conclusion and Recommendations

The goal of this project was to conduct preliminary analysis and design of a fast, reliable, and economically feasible underground transportation system in order to alleviate Asunción's traffic problem. This project presents a preliminary design for an underground public transportation system, to provide a fast and reliable solution. The end result is a tunnel that runs 21.25 kilometers, 20 meters under the city of Asunción. The expected infrastructure cost is of $90 million per kilometers, which ends up amounting to $2 billion. In contrast, the project will bring many benefits to the city and to commuters, the main one being a time reduction in the commute time from 80 minutes to 25 minutes, 70% less. Axiomatic Design Decomposition was used to identify the fundamental Functional Requirements and Design Parameters for the design, and an extensive cost benefit analysis assessed the potential benefits of the proposed solution. Several conclusions can be drawn from it, and they are explained in the following paragraphs

Axiomatic Design

Applying the Axiomatic Design at the start of this project was key to its successful completion. It allowed to define the problem at hand and guided our decision-making process for the activities that needed to be accomplished, and to create a graphical representation of the all the functions that our system needed to accomplish in order to be successful, since it included the parameters that might have had a smaller or larger impact on it. Once the Axiomatic Design was completed, we proceeded to develop the engineering design, and lastly, the cost benefit analysis. Axiomatic Design helped us to systematically address the issue, take into consideration all the main variables that would affect this project, and go forward with that knowledge. With this information in mind, it was possible able to navigate through the project knowing what sort of problems would appear, and action was taken accordingly. From this experience, it is concluded that Axiomatic Design can prove very useful in any type of project, especially if it is applied at the earlier phases of it, in that it will help the user not only determine the components that might affect the overall performance of the project, but also evaluate different alternatives against one another and guide the decision process of the stakeholders.

Engineering Design

The preliminary engineering design for the underground transportation system was performed based on several studies from other projects done in Paraguay and in the world. The project of the BRT currently being performed in the city of Asunción proved very useful in providing us with a lot of information regarding the current state of the city in term of population flow and public transportation capacity, as well as traffic studies. On the other hand, projects done in Beijing provided us with many of the technical data regarding to the construction of the tunnel itself. The design process was challenging many times however, due to the lack of data specific to our project. As it was discussed in earlier chapters, no two underground infrastructure projects are the same. There are conditions specific to the site in which they are develop that may completely change the way in which such a project is approached, such as segments of the horizontal alignment which has tubing that was not previously accounted for, a different type of soil, or foundations of an old structure that was brought down. In the specific case of Asunción, we are dealing with a soft soil with a relatively high water-table, similar to that of Beijing. However, Asunción is prone to flooding, which will most likely add extra maintenance costs, as well as probably change the design of the tunnel, which for example might want to place the electrical wiring in the top of the tunnel as opposed to the bottom, which is the normal practice.

It is so that there is a lot of research and further studies that should be done, specific to Asunción, to be able to more accurately determine the implications of such a project. Population flow and traffic studies should be performed on other areas of the city and not only on that corresponding to the alignment of the BRT to evaluate possible expansions and other lines to consider. It is recommended that, as the Plan Ceta (1998) was performed 15 years after the initial study in 1984, it is once again updated to evaluate how the city's behavior changed (in terms of population movements, growing trends, infrastructure, etc.) in the last two decades, compare that to the predictions made in 1998, and make future predictions that will guide better decisions in terms of policy and urban and traffic planning in the capital of Paraguay. Based on the researched studies as well as the conducted ones, a few more Metro lines were determined that are worth investigating in terms of feasibility, which can be seen in Figure 6-1. The red line connects our initial line and the city of Asunción with the city of Luque, the other big urbanization in the MRA, which will also connect to the main airport of the country, the hotel zone of Asunción, as well as a few of the biggest shopping malls and hospitals of the city. The green line will follow the alignment of Mcal. Lopez Avenue, which is one of the most congested streets of the city and provide another access to the "Centro." Lastly, the blue line will follow the street of Artigas, one with the worse congestion cases of the city, intersect with both the green and black lines, and lastly connect to the city of Lambaré, giving the people in this city an easier and faster commute to Asunción.

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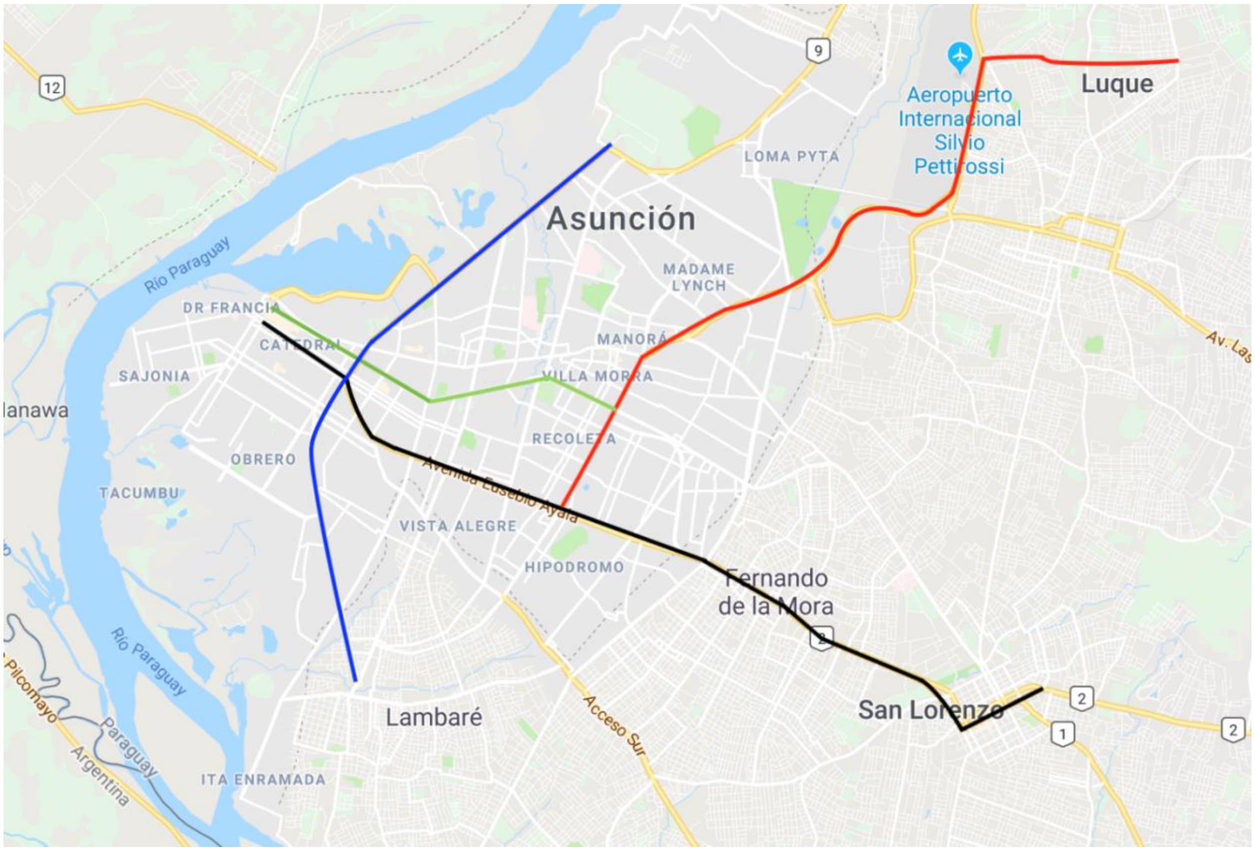

Figure 6-1. Alternative lines to consider, connecting Luque and Lambare

Cost Benefit Analysis

Similar to the engineering design, the cost benefit analysis was performed based on data from other projects. Infrastructure costs were considered from case studies of similar projects performed elsewhere, mainly in China, rolling stock costs were considered the same to a contract of the Bombardier firm for a project in California, and many of the commuting, pollution, car costs, among others, were retrieved from studies performed a in years past, some even twenty years ago (ironically the Plan Ceta, the most comprehensive traffic study performed on the city of Asunción). With this in mind, we had to convert many costs to the situation of Paraguay, either by bringing past costs to the present through engineering economic principles, adjusting them to account for the inflation trends as well as the growing tendencies of the population.

In view of this, further research and studies must be performed to be able to more accurately estimate the cost of such a system in the city of Asunción. With the current considerations and the base case of the study, the cost benefit ratio ended up being 2.32, meaning that the costs outweigh the benefits by more than twice on a span of 50 years, totaling an investment of $2.8 billion. There are however, benefits that cannot be quantified, such as the long term benefits a project of this magnitude will eventually bring the society and the development it will foster in the city. As it was explained in the Introduction and Problem Statement, only 5 Metro systems around the world generate income. The population, however, greatly benefits from it, and the quality of life is markedly improved.

On the other hand, other scenarios were considered, and in the best-case scenario the benefits outweigh the costs by almost 50%, with the costs being $1.4 billion, and in the worst-case scenario the costs outweigh the benefits by a factor of more than 5, reaching a total cost of more than $5 billion. These numbers however span over a big range, and more in-depth studies must be performed on site to narrow the numbers down.

Concluding remarks

Overall, this project was a great opportunity to analyze a system of such magnitude and become aware of all the implications it has in terms of its feasibility, constructability, and in the impact on the host city. It can be concluded that an underground transportation system will present a very attractive alternative to the commuters of the city of Asunción, reducing their commute time by 70%, and reducing costs of the car users by almost a factor of 10. On the other hand, the annual infrastructure budget of $900 million (MOPC budget, 2017) of Paraguay is relatively low to be able to implement such a system. There are cheaper alternatives, such as the BRT currently being built, that will still reduce the commuting time by 35% (refer to Section

4.6). Thus, it is recommended to look into other alternatives. However, if the population of the MRA continuous to grow, and the infrastructure budget increases, the Metro would be an alternative that should definitely be further investigated and pursued.

In another context, the MQP experience, along with other experiences at WPI such as the IQP and all the class projects we have performed in our time here have led us to recognize the value of continuous learning. The school has given us many tools to go forward in our careers, but the learning experience is far from being over. We live in an ever-changing world, technology is constantly advancing, as well as society, and we must keep up to date with such advancements. No problem it to big, as long as you are willing to dig into it, learn all that is to learn about it, and make your best effort to solve it.

Bibliography

Diario ABC Color (2016). “El BRT tendra una velocidad promedio de 24 kilometros por hora”. Retrieved from: http://www.abc.com.py/edicion-impresa/economia/el-BRT-tendra-una-velocidad-promedio-de-24-kiloMetros-por-hora-1459177.html

Beijing Metro line 4 opens. (2009). International Railway Journal, 49(11), 12.

Chang, Z. (2013). Public–private partnerships in china: A case of the Beijing no.4 Metro line.

Transport Policy, 30, 153-160. 10.1016/j.tranpol.2013.09.011

Clark, Gordon T. “Advanced Construction Techniques: Tunnels and Shafts.” University of Washington

Consorcio BRT Bus (November, 2011). “Análisis de Demanda y Diseño Operacional Informe Final: BRT Corredor Eusebio Ayala - Mcal. Estigarribia.”

Davidson, G., Howard, A., & Jacobs, L. (Eds.). (2014). North american tunneling 2014 proceedings: 2014 proceedings. Retrieved from https://ebookcentral-proquest-com.ezproxy.wpi.edu

Dirección General de Estadística, Encuestas y Censos (DGEEC, 2015). “Proyección de la población por sexo y edad, según distrito, 2000-2025

Fang, Qian. Zhang, Dingli. Ngai Yue Wong, Louis. (2012). “Shallow tunneling method (STM) for subway station construction in soft ground.” Tunneling and Underground Space technology. Retrieved from: http://www.sciencedirect.com.ezproxy.wpi.edu/science/article/pii/S0886779811001635

Franco, Rocio. Gomex, Rodney. Ramirez, Leticia (2006). “Carta Geotecnica de la Ciudad de Asunción”

Goel, R. K. Singh, Bhawani Zhao, Jian. (2012). Underground Infrastructures - Planning, Design, and Construction. Elsevier. Online version available at http://app.knovel.com/hotlink/toc/id:kpUIPDC002/underground-infrastructures/underground-infrastructures

Heritage (n.d). “2017 Index of Economic Freedom.” Retrieved September 21, 2017, from: http://www.heritage.org/index/country/paraguay

Li, X., Yuan, D., Guo, Y., Cai, Z. (2004). “Use of a 10.22 m diameter EPB shield: a case study in Beijing subway construction.” Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5121113/

Logit, Consorcio BRT Bus (May, 2015). “Estudios Complementarios de Demanda y de Alternativas de Trazado para el BRT Asunción-San Lorenzo.”

Logit, Consorcio BRT Bus (March, 2016). “Revisión del Modelo Financiero del BRT: BRT Asunción-San Lorenzo”

Lopez, F. (2017). “Metros de San Francisco: Inversiones para superar la crisis de madurez.” Via Libre Magazine. November 2017.

MacKechnie, Christopher. (2017). “The true operating costs between bus and light rail.” ThoughtCo. Retrieved from: https://www.thoughtco.com/bus-and-light-rail-costs-2798852

Másilková, M. (2017, February 03). Health and social consequences of road traffic accidents. Retrieved February 12, 2018, from: https://www.sciencedirect.com/science/article/pii/S1212411717300107?via%3Dihub

Nations Encyclopedia (2017). Paraguay. Retrieved September 21, 2017, from: http://www.nationsencyclopedia.com/economies/Americas/Paraguay.html

Nunns, Peter (2016). "The costs of tunneling." Greater Auckland. Retrieved From: https://www.greaterauckland.org.nz/2016/10/05/the-costs-of-tunnelling/

Office of Financial Management of The State of Washington, 2015. "Guidelines for Determining Architect/Engineer Fees for Public Works Building Projects". Retrieved from: https://www.ofm.wa.gov/sites/default/files/public/legacy/budget/instructions/capinst/aeguidelines.pdf

Park, G. (2010). Analytic Methods for Design Practice. Retrieved from: http://www.springer.com/us/book/9781846284724

Pour, Hamed Hashem (2016). “Study of Parameters impacting productivity of tunnel boring machines”. The University of Texas at Aarlington. Retrieved from: https://uta-ir.tdl.org/uta-ir/bitstream/handle/10106/26451/HASHEMPOUR-THESIS-2016.pdf?sequence=1

Pyrgidis, Christos (2016). Railway Transportation Systems: Design, Construction, and Operation. Retrieved September 26th, 2017, from: http://www.crcnetbase.com/doi/book/10.1201/b19472

Sfeir, R. (2007). Energy efficiency assessment of Bay Area Rapid Transit Train Cars. Retrieved from: https://www.bart.gov/sites/default/files/docs/BARTenergyreport.pdf

Suh, N. P. (2001). Axiomatic Design: advances and applications. New York: Oxford University Press.

Suzuki, Hiroaki. Cervero, Robert. Iuchi, Kanako (2013). Transforming Cities with Transit: Transit and Land-Use Integration for Sustainable Urban Development. Urban development. Washington, DC: World Bank. © World Bank. Retrieved September 19th, 2017, from https://openknowledge.worldbank.org/handle/10986/12233 License: CC BY 3.0 IGO." (Could be good to introduction and certain information)

Tanaka, Y., Marin, E., Yachiyo Engineering Co. Ltd. (October, 1999). Plan CETA 1998: Estudio de observación acerca de la planificación del transporte urbano en el área Metropolitana de Asunción.

TomTom International BV (2017). TomTom Traffic Index: Measuring Congestion Worldwide. Retrieved from https://www.tomtom.com/en_gb/trafficindex/about

World Population (November 20, 2016). Paraguay Population. Retrieved September 16th, 2017, from http://worldpopulationreview.com/countries/paraguay-population/

World Atlas (April, 2017). South America/ Paraguay. Retrieved September 16, 2017, from http://www.worldatlas.com/webimage/countrys/samerica/py.htm#page

Zegras, Christopher (1997). "An Analysis of the full costs and impacts of transportation in Santiago de Chile.

Appendix

Appendix A: Passenger flow of BRT

Table 0-1. Passenger flow of BRT analysis

Metrobus Trip Analysis with Passeger Flow[3]														
Station Number					To San Lorenzo					To Asuncion				
		Coordinates		Distance (km) (From 0-1, 1-2, etc)	Boardings	Exit	Passenger Load	Time to SL (min)	Speed (km/h)	Boardings	Exit	Passenger Load	Time to Asuncion (min)	Speed (km/h)
0	Terminal Asuncion	-25.277863, -57.652966		0.85	0	0	0	3	17	0	1821	0	3	17
1	Station 1 (Hospital Militar Central)	-25.278598, -57.645489		0.6	375	0	0	4	9	0	619	1821	2	18
2	Montevideo	-25.281722, -57.641852		0.95	328	0	375	5	11.4	0	938	2440	5	11.4
3	Nsa. De La Asuncion	-25.284942, -57.636284		0.6	373	0	703	2	18	2	1430	3376	2	18
4	Antequera	-25.287900, -57.631066		0.6	1005	0	1076	3	12	2	2313	4804	3	12
5	Station 5 (Brasil)	-25.290709, -57.626101		0.8	631	465	1616	3	16	860	1126	6257	3	16
6	Silvio Pettirossi	-25.296231, -57.623746		1	799	149	2098	4	15	20	1443	7363	4	15
7	Gral. Aquino	-25.299241, -57.621840		0.9	631	49	2848	2	27	18	1647	8788	2	27
8	Gral. M. Santos	-25.302940, -57.613916		0.5	268	68	3411	1	30	67	852	10368	1	30
9	Ciudad del Vaticano	-25.304409, -57.609436		0.85	323	41	3638	3	17	54	733	11166	2	25.5
10	Pariri	-25.306310, -57.603381		0.75	224	28	3933	2	22.5	81	385	11818	2	22.5
11	Choferes del Chaco	-25.308612, -57.596297		0.9	230	30	4127	3	18	109	583	12094	2	27
12	Victor Indoyaga	-25.311207, -57.589087		0.25	64	29	4328	1	15	46	116	12631	1	15
13	Rep. Argentina	-25.312022, -57.586764		1	374	171	4221	1	60	716	1256	12031	2	30
14	Hipodromo	-25.313810, -57.581568		0.85	75	45	4550	2	25.5	39	217	13248	2	25.5
15	La Victoria	-25.316475, -57.574016		0.6	105	160	4465	1	36	249	333	13216	1	36
16	Incas	-25.318051, -57.568373		0.8	86	348	4222	2	24	113	401	13436	1	48
17	Calle Ultima	-25.320203, -57.560762		1.3	493	181	4127	4	19.5	276	1427	13561	1	78
18	28 de Febrero	-25.322419, -57.556119		0.65	180	302	4318	4	9.75	779	449	14209	2	19.5
19	Campo Santo	-25.325223, -57.550770		0.6	226	507	3991	2	18	1357	628	13301	2	18
20	Ytororo	-25.328069, -57.546048		0.8	110	348	3869	2	24	354	353	13575	2	24
21	Leopardi	-25.332438, -57.540084		0.5	113	266	3713	4	7.5	479	350	13449	2	15
22	Pastora Cepedes	-25.334290, -57.535932		0.6	114	231	3595	6	6	314	172	13485	4	9
23	Emilio Cubas	-25.336317, -57.530515		0.9	90	569	3140	5	10.8	835	265	12822	7	7.714285714
24	Universidad de Asuncion	-25.338845, -57.523660		1.5	74	584	2646	5	18	556	270	12531	11	8.181818182
25	Mercado	-25.347952, -57.513862		0.75	78	386	2334	4	11.25	1130	27	11671	4	11.25
26	Coronel Romero	-25.344933, -57.507339		0.85	200	566	1846	4	12.75	1834	20	9864	4	12.75
27	Terminal San Lorenzo	-25.340795, -57.500993			0	2046	0			9884	0	0		
			Total Length	21.25										

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Appendix B: Cost Benefit Analysis Excel Sheet Walkthrough

The following section is an explanation of the excel sheet that contains our calculations for the cost benefit analysis. So far, the cost benefit analysis itself was done using unique values. We have determined ranges for most of the factors that are involved in the analysis, however, unique values were used for the model purposes.

Cost Benefit

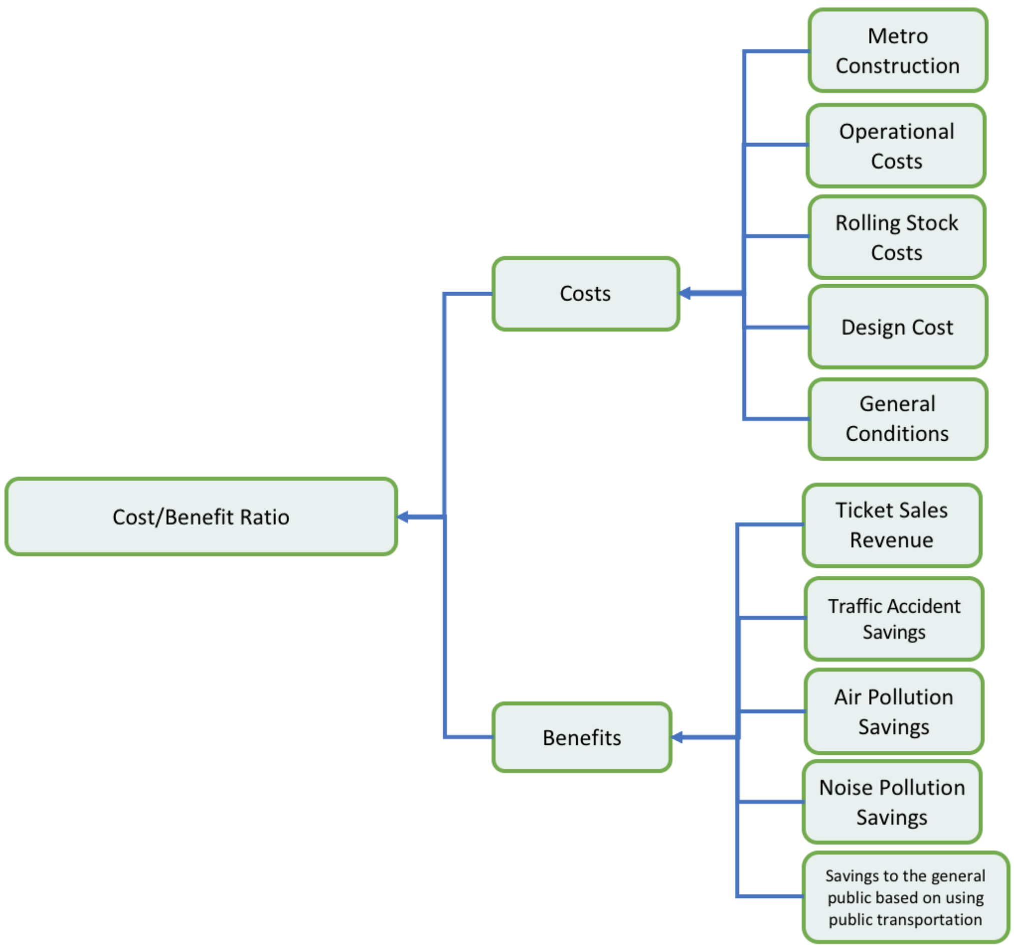

Figure 0-1. General components affecting the cost benefit ratio

This tab summarizes and brings together the data developed in other tabs that relates to costs and benefits that arise from this project. The Guarani/Dollar cell is a cell that is related to other cells in other tabs. If this is changed, the change happens in the Public Transportation Costs, Car Costs, and Fuel Costs. Then the tab presents information related to the project, such as the layout length, which was determined from the "BRT Trip Analysis with Passenger Flow" Table in the Public Transportation costs tab. The Metro construction cost was determined from the cost per kilometer of a similar project done in Beijing and multiplied by the expected length of our project. This project was considered because it has very similar soil conditions as those in Asunción. The costs were also adapted based on a factor that considered the minimum wage of that in Paraguay and in China. The inflation rate comes from the "Inflation 1997-2017" tab. However, the number we used, which is a 3.68%, is an average of the last five years. This value can be easily changed and the model adapts to it, so that we can see how it behaves under different inflation rates. We assumed the construction time to be 4 years, which is a little optimistic. However, we used this number considering different tunneling rates in places with similar conditions, which can be seen in the "Metro Construction Times" tab. This rate was of 15 m/day, which with our length of 21.25 km translates to slightly less than two years. The Metro construction per year cost is basically an annualized payment that comes out of the estimated value spread over the 4 years, with the specified inflation rate of 3.68%. The operating costs were determined from the current operating costs of the BRT, which can be seen in the "Annual Operating Costs" Table in Metro Cost. The annual ticket sales revenue was estimated in the "Ticket Sale Revenue" table from the "Public Transportation Cost" tab. An annual growth was used to estimate the new users of the system as part of the projected benefits of the ticket sales. All the costs and benefits in the "Projected Costs and Benefits" table were taken to the future to determine the value at each year until 2038, year that we considered as the end of a 20-year analysis period. We later did the same analysis for a 50-year period. This can be adjusted as well.

The tables below are the two main ones in the cost benefit tab, and show the different values explained earlier.

Guarani/USD	5555

Layout Length (km)	21.25
Metro Construction Cost ($)	$1,982,319,311.12
Inflation rate	3.68%
Capitalization rate[1]	8%
Construction time (years) [2]	4
Metro construction cost / year ($)	$598,503,441.10
Operating cost ($/year)	7654573.73
Rolling stock overhaul (yr)	25
Annual ticket sales revenue ($)	$55,107,881.47

Projected Cost and Benefits

	Present	Year	Present Values	2018	2019	2020	2021	2022	2023	2024
Cost	($2,726,089,397.01)	Metro construction ($)	$2,087,189,866.98	$598,503,441.10	$620,528,367.73	$643,363,811.66	$667,039,599.93	$0.00	$0.00	$0.00
		Operational costs ($)	$75,309,704.95	$0.00	$0.00	$0.00	$0.00	$8,845,063.69	$9,170,562.03	$9,508,038.72
		Rolling stock cost ($)	$146,151,851.69	$0.00	$0.00	$0.00	$0.00	$182,786,757.36	$11,147,841.77	$0.00
		Design cost (15%)	$313,078,480.05							
		General Conditions (5%	$104,359,493.35							
Benefit	$660,100,455.56	Ticket sales revenue ($)	$518,292,495.35	$0.00	$0.00	$0.00	$0.00	$55,107,881.47	$57,931,902.72	$60,900,641.86
		Traffic Accident Savings	$12,280,043.71	$0.00	$0.00	$0.00	$0.00	$1,305,685.88	$1,372,596.18	$1,442,935.31
		Air pollution savings ($)	$7,292,414.34	$0.00	$0.00	$0.00	$0.00	$775,372.03	$815,106.22	$856,876.61
		Noise Pollution savings	$1,008,091.11	$0.00	$0.00	$0.00	$0.00	$107,186.13	$112,678.92	$118,453.18
		Savings to users ($)	$121,227,411.05	$0.00	$0.00	$0.00	$0.00	$12,889,605.53	$13,550,137.54	$14,244,518.73

Year	2025	2026	2027	2028	2029	2030	2031
Metro construction ($)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Operational costs ($)	$9,857,934.54	$10,220,706.53	$10,596,828.53	$10,986,791.82	$11,391,105.76	$11,810,298.45	$12,244,917.44
Rolling stock cost ($)	$0.00	$0.00	$0.00	$13,355,671.80	$0.00	$0.00	$0.00
Design cost (15%)							
General Conditions (5%							
Ticket sales revenue ($)	$64,021,515.00	$67,302,318.29	$70,751,247.41	$74,376,918.02	$78,188,387.29	$82,195,176.55	$86,407,295.02
Traffic Accident Savings	$1,516,879.00	$1,594,611.96	$1,676,328.36	$1,762,232.35	$1,852,538.52	$1,947,472.46	$2,047,271.32
Air pollution savings ($)	$900,787.53	$946,948.67	$995,475.37	$1,046,488.82	$1,100,116.48	$1,156,492.31	$1,215,757.13
Noise Pollution savings	$124,523.35	$130,904.59	$137,612.84	$144,664.86	$152,078.25	$159,871.55	$168,064.22
Savings to users ($)	$14,974,483.71	$15,741,855.97	$16,548,552.48	$17,396,588.41	$18,288,082.22	$19,225,260.91	$20,210,465.63

Year	2032	2033	2034	2035	2036	2037	2038
Metro construction ($)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Operational costs ($)	$12,695,530.40	$13,162,725.92	$13,647,114.23	$14,149,328.03	$14,670,023.31	$15,209,880.16	$15,769,603.75
Rolling stock cost ($)	$15,432,834.27	$0.00	$0.00	$0.00	$17,833,050.79	$0.00	$0.00
Design cost (15%)							
General Conditions (5%							
Ticket sales revenue ($)	$90,835,264.86	$95,490,147.46	$100,383,571.02	$105,527,759.66	$110,935,563.92	$116,620,492.85	$122,596,747.82
Traffic Accident Savings	$2,152,184.40	$2,262,473.79	$2,378,414.99	$2,500,297.64	$2,628,426.20	$2,763,120.75	$2,904,717.77
Air pollution savings ($)	$1,278,059.00	$1,343,553.54	$1,412,404.38	$1,484,783.50	$1,560,871.71	$1,640,859.09	$1,724,945.44
Noise Pollution savings	$176,676.73	$185,730.59	$195,248.41	$205,253.98	$215,772.28	$226,829.60	$238,453.56
Savings to users ($)	$21,246,157.49	$22,334,923.71	$23,479,484.11	$24,682,697.87	$25,947,570.72	$27,277,262.38	$28,675,094.53

Cost Benefit Ratio	4.13

Figure 0-2. Calculation tables from the cost benefit tab

Metro Infrastructure Costs

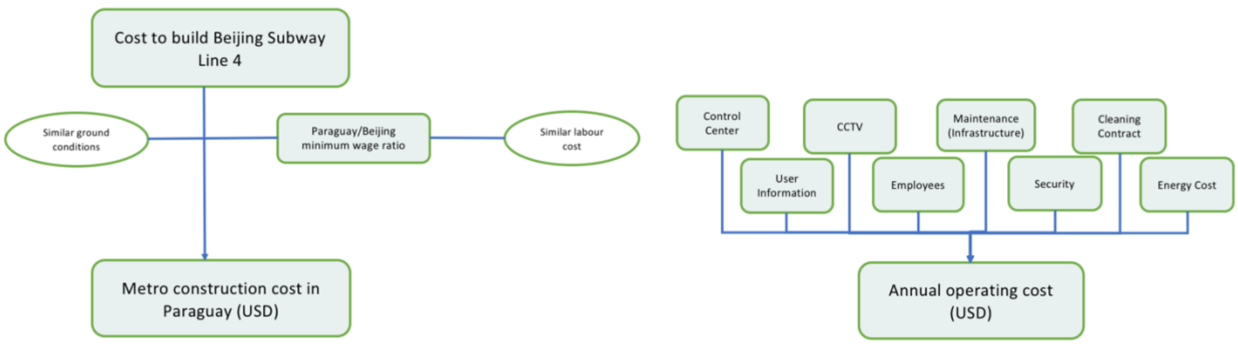

Figure 0-3. General components of the Metro cost infrastructure

This tab shows the costs considered for the Metro construction and its operation. The first costs are the minimum, maximum, and average costs of construction of subway projects in other places in the world, particularly from Barcelona and Beijing. Thus, the minimum of $40 M and maximum of $170 M (both of those projects were in Barcelona), with an average of $105 M. The cost to build a Metro in Beijing was taken from that of the line 4 in Beijing (which can be seen in the "Construction Costs" tab), which is used as a benchmark to estimate the cost in Paraguay, since the soil of both places are very similar, and the labor cost is similar. We used the minimum wages of both countries to create a ratio by which we multiplied the construction cost of the project in China to get an estimate of the project in Paraguay.

Considering that stations account for 30% of the total infrastructure costs, we determined the cost per stations by dividing the total cost of the project by the 24 stations it had planned. The other 70% corresponds to the tunnel between stations, which we divided by 28.8 (the total length of the system), in order to get the cost per km of tunnel. Based on the expected number of stations and the expected length of the system in Asunción, we found the total cost for a system of our dimensions, which we multiplied by the minimum wage ratio of China and Paraguay to get the actual cost of the system.

Metro construction cost [1]	
Min cost/km	$40,000,000.00
Max cost/km	$170,000,000.00
Mean cost/km	$105,000,000.00
Cost to build a metro line in Beijing per km (RMB) (2013) [2]	¥542,553,191.49
Cost to build a metro line in Beijing per km (USD) (2017)	$82,168,817.00
Total Beijing cost per station[7]	$28,964,507.99
Total Beijing cost per km of tunneling	$57,518,171.90
Minimum wage Beijing [3]	$302.18
Minimum wage Paraguay	$368
Minimum wage ratio	1.22
Number of stations in Beijing Line 4	24
Number of expected stations in Asuncion	14.00
Station Cost as fraction of total cost	30%
Estimated cost per station in Asuncion	$35,273,475.88
Estimated cost per km of tunneling in Asuncion	$70,046,618.77
Total cost of a metro line in Paraguay	$1,982,319,311.12
Estimated construction cost in Paraguay per km	$93,285,614.64
Infrastructure Lifespan	100

CPI 2008	232.9
CPI 2017	244.79
RMB (2013)/USD	6.94

Figure 0-4. Metro construction costs

Then we considered the “Annual Operating Costs”. These were taken from a study done for the BRT. It considers control center costs, user information costs, CCTV operation and maintenance, employee wages, infrastructure maintenance, security personnel, and cleaning staff. We made an adaptation of these costs based on the number of stations of the BRT project (28), as well as the expected number of Metro stations. We also factored in the difference in operating a BRT to that of a Metro system, considering that the costs to operate a Metro is almost twice than that of a BRT. In addition to this adapted cost, we considered the energy consumption of the carts, which depends on the maximum number of carts that we are considering for the 50-year plan (which ends up being 120).

Annual Operational Costs (metrobus adapted to metro) ($) [4]	
Control center	$3,679,000.00
User information	$360,000.00
CCTV	$258,000.00
Employees	$1,350,000.00
Maintenance (infrastructure)	$161,398.00
Security posts contract	$716,700.00
Cleaning Contract	$249,000.00
Energy consumption per cart per year (kWh) [5]	449,108.70
Energy cost in Paraguay ($/kWh) [6]	$0.04
Metro/metrobus operating cost ratio[8]	1.91
Number of carts	75.00
Total cost of energy consumption	$1,185,310.14
Total	$12,938,527.18
Number of metrobus stations	28
Number of metro stations	14.00
Adjusted Annual operating costs for metro	$7,654,573.73

Figure 0-5. Annual operating costs

Public Transportation Costs

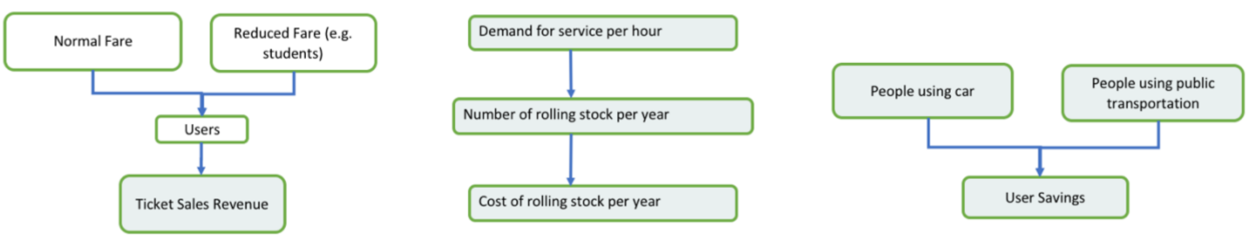

Figure 0-6. General components of the public transportation cost

In this tab we calculated the public transportation costs to evaluate possible savings. First, we did the "BRT Trip Analysis with Passenger Flow," in which we determined the actual coordinates for each station, as well the distance between each station. In it there is information regarding the number of boarding and disembarks on each station and on each direction (towards San Lorenzo and towards Asunción). From those numbers we were able to determine the number of passengers in the system at each segment of the layout. From Google Maps we were able to determine the time it took to go from each station to the next at peak hour. This data is useful to determine the time it would take a normal car or bus to run that same transect.

Guarani/USD	5555

Type	Cost per Trip (Guarani)	Cost (USD)
Bus [1]	2100	0.38
Bus (Air Conditioner)[1]	3300	0.59
Metrobus[2]	4464	0.80

					Metrobus Trip Analysis with Passeger Flow[3]									
					To San Lorenzo					To Asuncion				
Station Number	Station	Coordinates		Distance (km) (From 0-1, 1-2, etc)	Boardings	Exit	Passenger Load	Time to SL (min)	Speed (km/h)	Boardings	Exit	Passenger Load	Time to Asuncion (min)	Speed (km/h)
0	Terminal Asuncion	-25.277863, -57.652966		0.85	0	0	0	3	17	0	1821	0	3	17
1	Station 1 (Hospital Militar Central)	-25.278598, -57.645489		0.6	375	0	0	4	9	0	619	1821	2	18
2	Montevideo	-25.281722, -57.641852		0.95	328	0	375	5	11.4	0	938	2440	5	11.4
3	Nsa. De La Asuncion	-25.284942, -57.636284		0.6	373	0	703	2	18	2	1430	3376	2	18
4	Antequera	-25.287900, -57.631066		0.6	1005	0	1076	3	12	2	2313	4804	3	12
5	Station 5 (Brasil)	-25.290709, -57.626101		0.8	631	465	1616	3	16	860	1126	6257	3	16
6	Silvio Pettirossi	-25.296231, -57.623746		1	799	149	2098	4	15	20	1443	7363	4	15
7	Gral. Aquino	-25.299241, -57.621840		0.9	631	49	2848	2	27	18	1647	8788	2	27
8	Gral. M. Santos	-25.302940, -57.613916		0.5	268	68	3411	1	30	67	852	10368	1	30
9	Ciudad del Vaticano	-25.304409, -57.609436		0.85	323	41	3638	3	17	54	733	11166	2	25.5
10	Pariri	-25.306310, -57.603381		0.75	224	28	3933	2	22.5	81	385	11818	2	22.5
11	Choferes del Chaco	-25.308612, -57.596297		0.9	230	30	4127	3	18	109	583	12094	2	27
12	Victor Indoyaga	-25.311207, -57.589087		0.25	64	29	4328	1	15	46	116	12631	1	15
13	Rep. Argentina	-25.312022, -57.586764		1	374	171	4221	1	60	716	1256	12031	2	30
14	Hipodromo	-25.313810, -57.581568		0.85	75	45	4550	2	25.5	39	217	13248	2	25.5
15	La Victoria	-25.316475, -57.574016		0.6	105	160	4465	1	36	249	333	13216	1	36
16	Incas	-25.318051, -57.568373		0.8	86	348	4222	2	24	113	401	13436	1	48
17	Calle Ultima	-25.320203, -57.560762		1.3	493	181	4127	4	19.5	276	1427	13561	1	78
18	28 de Febrero	-25.322419, -57.556119		0.65	180	302	4318	4	9.75	779	449	14209	2	19.5
19	Campo Santo	-25.325223, -57.550770		0.6	226	507	3991	2	18	1357	628	13301	2	18
20	Ytororo	-25.328069, -57.546048		0.8	110	348	3869	2	24	354	353	13575	2	24
21	Leopardi	-25.332438, -57.540084		0.5	113	266	3713	4	7.5	479	350	13449	2	15
22	Pastora Cepedes	-25.334290, -57.535932		0.6	114	231	3595	6	6	314	172	13485	4	9
23	Emilio Cubas	-25.336317, -57.530515		0.9	90	569	3140	5	10.8	835	265	12822	7	7.71428571
24	Universidad de Asuncion	-25.338845, -57.523660		1.5	74	584	2646	5	18	556	270	12531	11	8.18181818
25	Mercado	-25.347952, -57.513862		0.75	78	386	2334	4	11.25	1130	27	11671	4	11.25
26	Coronel Romero	-25.344933, -57.507339		0.85	200	566	1846	4	12.75	1834	20	9864	4	12.75
27	Terminal San Lorenzo	-25.340795, -57.500993			0	2046	0			9884	0	0		
			Total Length	21.25										

Figure 0-7. Passenger flow analysis for the BRT system

With the information of the distance between station, the number of passengers in the system, as well as the boarding to the system we were able to determine the average distance that people travel in the direction towards Asunción and in the direction towards San Lorenzo, which ended up being an average of 9.44 km of travel distance. This information is useful since it allowed us to estimate the costs due to pollution and accidents, as well as the estimate for the cost of trips, since we could refer to it as a mean distance travelled. The way this factor was calculated was the following:

$$Average\ distance\text{:}\ \frac{\Sigma(Distance * Passengers\ in\ the\ system)}{\Sigma Boardings}$$

We then calculated the Metro trip cost. For it we used the estimated annual passenger volume of the BRT, which we got from the BRT study, and from which we were able to narrow it down to an average daily volume. The margin of 5% specified refers to the passenger volume, and was specified in the BRT studies, which we used to make a range for the estimate of ticket sales revenue in the next tale. The average distance of the trip was calculated as specified in the previous paragraph, and the cost per trip was based out of the BRT ticket fare. This yielded a Metro trip cost per kilometer of $0.09.

The following table calculates the total ticket sale revenue, which considers the low and high end based on the five percent margin. It also takes into consideration the student population, which is going to have a cheaper fare, as well as the percentage of the users which are students.

Average distance travelled in one singel direction	
Average distance towards San Lorenzo (km)	8.17
Average distance towards Asuncion (km)	10.71

Metro trip cost calculation	
Annual passenger volume[3]	69097221.00
Average daily volume	189307.45
Margin	5%
Average distance of trip (km)	9.44
Cost per trip (G)	4464
Cost per trip ($)	$0.80
Metro trip cost/km ($)	$0.09

Ticket Sale Revenue	
Student (% of population)[4]	10.96%
Student ticket fare	50.00%
Ticket Sales Revenue	$52,483,696.64
Ticket Sale Revenue Low	$49,859,511.81
Ticket Sale Revenue High	$55,107,881.47

Figure 0-8. Calculation of Metro cost trip

The next table provides information that is going to feed into the Passenger volume per hour table. It provides a calculated frequency of the trains which is based on the number of trains considered, the speed at which these are going to operate, the distance covered by the layout, the number of stops and the time it takes at each stop. Then there is the train capacity, which we based out of Stadler and Bombardier trucks, which have a crush load of 200, but we considered 170 passengers to account for the factor of comfort. The following cells specify the number of motor cars, which are the ones at the end, and the intermediate trailer cars. These can be modified, which in the end affects the total volume of passengers the system can transport. The total number of rolling stock is then calculated by the number of rolling stock (motor and intermediate trains) per train, and the number of trains in the system which are required to move the estimated people in the system hourly. The capacity of the system is based on the amount of rolling stock and the capacity of each of these, and the capacity of the system per direction is the same as that of the system divided by two. The cost of the rolling stock was estimated from a case study from the company Bombardier and its contract with the San Francisco Bay Area BART system. Then we used the population growth, which was calculated in the "Annual Growth" table, and the inflation rate, to project the increase of the users throughout the years, and estimate the cost of the rolling stock, as well as the years in which new rolling stock should be bought. The "Passenger volume per hour" table is distributed by time frames, and each time is assigned a factor which accounts for the volume of people. 1 means it is peak hour, 0.2 means there is basically no people at all. The 0.9 non-peak reduction factor was extracted from the Plan Ceta. Then we have columns for each year, which are separated between two columns each. The first one, which is titled with a number, specifies the peak hour volume of passengers in both directions of the system. This is the value that determines the hourly passenger volume per direction, which is specified in the cells below it. It is important to understand that these cells refer to the one-way hourly flow. The other column refers to the number of trains needed according to the hourly volume. From this numbers, we can determine the number of rolling stock needed per year, to which we added 5 extra rolling-stock (two motors and three intermediate) as safety units. This allows us to finally determine the cost per year of rolling stock, as well as helps us visualize the years in which new investments will be needed as more rolling stock are required.

Trip information	
Frequency (min)	4.02
Operating Speed (km/h)	50.00
Distance (km)	21.25
Time/km (min)	1.20
Stops	14.00
Time per stop (min)	0.33
Total time to complete 1 length	30.17
Train capacity [5]	170.00
Number of trains	15.00
Number of motor cars	2.00
Number of intermediate trailer cars	3.00
Number of rolling stock per train	5.00
Total number of rolling stock	75.00
Capacity of the system (people/hour)	12750.00
Capacity of the system per direction (people/hour)	6375.00
Cost per rolling stock [6]	$1,794,943.82

Population annual growth	1.01

Inflation rate	3.68%
Capitalization rate	8%

Figure 0-9. Calculations for the train capacity and frequency

Passenger volume per hour — Passengers/hour/direction

Time	Year	2017		2018		2019		2020		2021		2022	
	Peak Hour Volume / Peak Hour Factor	12537	Number of trains	12712	Number of trains	12889	Number of trains	13068	Number of trains	13250	Number of trains	13435	Number of trains
5am-6am	0.9	5642	14	5720	14	5800	14	5881	14	5963	15	6046	15
6am-7am	1	6269	15	6356	15	6444	16	6534	16	6625	16	6718	16
8am-9am	1	6269	15	6356	15	6444	16	6534	16	6625	16	6718	16
9am-10am	0.9	5642	14	5720	14	5800	14	5881	14	5963	15	6046	15
10am-11am	0.9	5642	14	5720	14	5800	14	5881	14	5963	15	6046	15
11am-12pm	0.9	5642	14	5720	14	5800	14	5881	14	5963	15	6046	15
12pm-1pm	0.9	5642	14	5720	14	5800	14	5881	14	5963	15	6046	15
1pm-2pm	0.9	5642	14	5720	14	5800	14	5881	14	5963	15	6046	15
2pm-3pm	0.9	5642	14	5720	14	5800	14	5881	14	5963	15	6046	15
3pm-4pm	0.9	5642	14	5720	14	5800	14	5881	14	5963	15	6046	15
4pm-5pm	0.9	5642	14	5720	14	5800	14	5881	14	5963	15	6046	15
5pm-6pm	1	6269	15	6356	15	6444	16	6534	16	6625	16	6718	16
6pm-7pm	1	6269	15	6356	15	6444	16	6534	16	6625	16	6718	16
7pm-8pm	1	6269	15	6356	15	6444	16	6534	16	6625	16	6718	16
8pm-9pm	0.9	5642	14	5720	14	5800	14	5881	14	5963	15	6046	15
9pm-10pm	0.5	3134	8	3178	8	3222	8	3267	8	3313	8	3359	8
10pm-11pm	0.4	2507	6	2542	6	2578	7	2614	7	2650	7	2687	7
11pm-12am	0.2	1254	3	1271	3	1289	4	1307	4	1325	4	1344	4
Number of rolling stock per year		75		75		80		80		80		80	
Number of rolling stock + safety rolling stock		80		80		85		85		85		85	
Unit cost of rolling stock per year		$1,794,944		$1,860,998		$1,929,482		$2,000,487		$2,074,105		$2,150,432	
Cost of rolling stock per year		$0		$0		$0		$0		$0		$182,786,757	

Time	Year	2023		2024		2025		2026		2027		2028	
	Peak Hour Volume / Peak Hour Factor	13622	Number of trains	13812	Number of trains	14004	Number of trains	14200	Number of trains	14397	Number of trains	14598	Number of trains
5am-6am	0.9	6130	15	6215	15	6302	15	6390	16	6479	16	6569	16
6am-7am	1	6811	17	6906	17	7002	17	7100	17	7199	17	7299	18
8am-9am	1	6811	17	6906	17	7002	17	7100	17	7199	17	7299	18
9am-10am	0.9	6130	15	6215	15	6302	15	6390	16	6479	16	6569	16
10am-11am	0.9	6130	15	6215	15	6302	15	6390	16	6479	16	6569	16
11am-12pm	0.9	6130	15	6215	15	6302	15	6390	16	6479	16	6569	16
12pm-1pm	0.9	6130	15	6215	15	6302	15	6390	16	6479	16	6569	16
1pm-2pm	0.9	6130	15	6215	15	6302	15	6390	16	6479	16	6569	16
2pm-3pm	0.9	6130	15	6215	15	6302	15	6390	16	6479	16	6569	16
3pm-4pm	0.9	6130	15	6215	15	6302	15	6390	16	6479	16	6569	16
4pm-5pm	0.9	6130	15	6215	15	6302	15	6390	16	6479	16	6569	16
5pm-6pm	1	6811	17	6906	17	7002	17	7100	17	7199	17	7299	18
6pm-7pm	1	6811	17	6906	17	7002	17	7100	17	7199	17	7299	18
7pm-8pm	1	6811	17	6906	17	7002	17	7100	17	7199	17	7299	18
8pm-9pm	0.9	6130	15	6215	15	6302	15	6390	16	6479	16	6569	16
9pm-10pm	0.5	3406	9	3453	9	3501	9	3550	9	3599	9	3650	9
10pm-11pm	0.4	2724	7	2762	7	2801	7	2840	7	2879	7	2920	7
11pm-12am	0.2	1362	4	1381	4	1400	4	1420	4	1440	4	1460	4
Number of rolling stock per year		85		85		85		85		85		90	
Number of rolling stock + safety rolling stock		90		90		90		90		90		95	
Unit cost of rolling stock per year		$2,229,568		$2,311,616		$2,396,684		$2,484,882		$2,576,326		$2,671,134	
Cost of rolling stock per year		$11,147,842		$0		$0		$0		$0		$13,355,672	

Time	Year	2029		2030		2031		2032		2033	
	Peak Hour Volume / Peak Hour Factor	14801	Number of trains	15008	Number of trains	15217	Number of trains	15429	Number of trains	15644	Number of trains
5am-6am	0.9	6661	16	6753	16	6848	17	6943	17	7040	17
6am-7am	1	7401	18	7504	18	7608	18	7714	19	7822	19
8am-9am	1	7401	18	7504	18	7608	18	7714	19	7822	19
9am-10am	0.9	6661	16	6753	16	6848	17	6943	17	7040	17
10am-11am	0.9	6661	16	6753	16	6848	17	6943	17	7040	17
11am-12pm	0.9	6661	16	6753	16	6848	17	6943	17	7040	17
12pm-1pm	0.9	6661	16	6753	16	6848	17	6943	17	7040	17
1pm-2pm	0.9	6661	16	6753	16	6848	17	6943	17	7040	17
2pm-3pm	0.9	6661	16	6753	16	6848	17	6943	17	7040	17
3pm-4pm	0.9	6661	16	6753	16	6848	17	6943	17	7040	17
4pm-5pm	0.9	6661	16	6753	16	6848	17	6943	17	7040	17
5pm-6pm	1	7401	18	7504	18	7608	18	7714	19	7822	19
6pm-7pm	1	7401	18	7504	18	7608	18	7714	19	7822	19
7pm-8pm	1	7401	18	7504	18	7608	18	7714	19	7822	19
8pm-9pm	0.9	6661	16	6753	16	6848	17	6943	17	7040	17
9pm-10pm	0.5	3700	9	3752	9	3804	9	3857	10	3911	10
10pm-11pm	0.4	2960	7	3002	8	3043	8	3086	8	3129	8
11pm-12am	0.2	1480	4	1501	4	1522	4	1543	4	1564	4
Number of rolling stock per year		90		90		90		95		95	
Number of rolling stock + safety rolling stock		95		95		95		100		100	
Unit cost of rolling stock per year		$2,769,432		$2,871,347		$2,977,013		$3,086,567		$3,200,153	
Cost of rolling stock per year		$0		$0		$0		$15,432,834		$0	

Time	Year	2034		2035		2036		2037		2038	
	Peak Hour Volume / Peak Hour Factor	15862	Number of trains	16083	Number of trains	16307	Number of trains	16534	Number of trains	16764	Number of trains
5am-6am	0.9	7138	17	7237	18	7338	18	7440	18	7544	18
6am-7am	1	7931	19	8041	19	8153	20	8267	20	8382	20
8am-9am	1	7931	19	8041	19	8153	20	8267	20	8382	20
9am-10am	0.9	7138	17	7237	18	7338	18	7440	18	7544	18
10am-11am	0.9	7138	17	7237	18	7338	18	7440	18	7544	18
11am-12pm	0.9	7138	17	7237	18	7338	18	7440	18	7544	18
12pm-1pm	0.9	7138	17	7237	18	7338	18	7440	18	7544	18
1pm-2pm	0.9	7138	17	7237	18	7338	18	7440	18	7544	18
2pm-3pm	0.9	7138	17	7237	18	7338	18	7440	18	7544	18
3pm-4pm	0.9	7138	17	7237	18	7338	18	7440	18	7544	18
4pm-5pm	0.9	7138	17	7237	18	7338	18	7440	18	7544	18
5pm-6pm	1	7931	19	8041	19	8153	20	8267	20	8382	20
6pm-7pm	1	7931	19	8041	19	8153	20	8267	20	8382	20
7pm-8pm	1	7931	19	8041	19	8153	20	8267	20	8382	20
8pm-9pm	0.9	7138	17	7237	18	7338	18	7440	18	7544	18
9pm-10pm	0.5	3965	10	4021	10	4077	10	4133	10	4191	10
10pm-11pm	0.4	3172	8	3217	8	3261	8	3307	8	3353	8
11pm-12am	0.2	1586	4	1608	4	1631	4	1653	4	1676	4
Number of rolling stock per year		95		95		100		100		100	
Number of rolling stock + safety rolling stock		100		100		105		105		105	
Unit cost of rolling stock per year		$3,317,918		$3,440,018		$3,566,610		$3,697,861		$3,833,943	
Cost of rolling stock per year		$0		$0		$17,833,051		$0		$0	

Figure 0-10. Rolling stock calculation based on peak hour demand

The last table provides the savings that the general users will gain by switching from using private vehicles to public transportation, particularly the Metro. The table considers the car cost per kilometer driven, the Metro trip cost per kilometer, and projects these costs into the future by accounting for inflation, currently estimated to be 3.68%. We then considered the number of cars in Asunción for each of those years and based on these values found the total cost of the entire population using private vehicles, considering a daily roundtrip of 18.44 km for 260 working days. We then assumed the same population would take the public transportation, and using the same approach just mentioned found the total cost for this setting. Following that, we found the difference for each year between these two costs, which would suppose the savings of the entire population, assuming 100% of them shifted to using public transportation. Since that is not accurate, we applied the reducing factor of 0.49%, which estimates the number of users that are going to actually shift to the public transportation.

Car cost per km ($)	$0.89
Metro trip cost/km ($)	$0.09
Car reduction factor	0.0049

Year	2018	2019	2020	2021	2022	2023	2024
Car cost per km ($)	0.927100361	0.961217655	0.996590464	1.033264993	1.071289145	1.110712586	1.151586809
Metro trip cost/km ($)	0.088230639	0.091477527	0.0948439	0.098334155	0.101952852	0.105704717	0.109594651
Expected number of vehicles	524824	532136	539550	547067	554689	562417	570253
Travel Cost using car	$2,395,800,314.47	$2,518,573,877.41	$2,647,639,011.34	$2,783,318,129.85	$2,925,950,168.73	$3,075,891,432.63	$3,233,516,485.15
Travel Cost using metro	$228,004,434.59	$239,688,595.67	$251,971,515.37	$264,883,877.27	$278,457,937.34	$292,727,604.51	$307,728,525.40
Cost difference	$2,167,795,879.88	$2,278,885,281.74	$2,395,667,495.97	$2,518,434,252.58	$2,647,492,231.39	$2,783,163,828.12	$2,925,787,959.75
Savings (with reduction factor)	$10,554,151.37	$11,095,002.28	$11,663,569.26	$12,261,272.65	$12,889,605.53	$13,550,137.54	$14,244,518.73

Year	2025	2026	2027	2028	2029	2030	2031
Car cost per km ($)	1.193965203	1.237903123	1.283457958	1.330689211	1.379658574	1.430430009	1.483069833
Metro trip cost/km ($)	0.113627734	0.117809235	0.122144615	0.126639536	0.131299871	0.136131707	0.141141353
Expected number of vehicles	578199	586254	594422	602704	611101	619616	628249
Travel Cost using car	$3,399,219,084.53	$3,573,413,167.28	$3,756,533,882.21	$3,949,038,677.47	$4,151,408,443.30	$4,364,148,713.32	$4,587,790,927.36
Travel Cost using metro	$323,498,173.34	$340,075,941.99	$357,503,243.76	$375,823,613.25	$395,082,816.02	$415,328,962.86	$436,612,630.06
Cost difference	$3,075,720,911.20	$3,233,337,225.30	$3,399,030,638.45	$3,573,215,064.22	$3,756,325,627.28	$3,948,819,750.46	$4,151,178,297.30
Savings (with reduction factor)	$14,974,483.71	$15,741,855.97	$16,548,552.48	$17,396,588.41	$18,288,082.22	$19,225,260.91	$20,210,465.63

Year	2032	2033	2034	2035	2036	2037	2038
Car cost per km ($)	1.537646803	1.594232206	1.652899951	1.713726669	1.77679181	1.842177749	1.90996989
Metro trip cost/km ($)	0.146335355	0.151720496	0.157303811	0.163092591	0.169094398	0.175317072	0.18176874
Expected number of vehicles	637002	645877	654876	664000	673251	682631	692142
Travel Cost using car	$4,822,893,759.09	$5,070,044,511.55	$5,329,860,584.37	$5,602,991,015.97	$5,890,118,104.98	$6,191,959,114.65	$6,509,268,064.61
Travel Cost using metro	$458,986,985.67	$482,507,922.39	$507,234,197.12	$533,227,577.81	$560,552,997.70	$589,278,717.59	$619,476,496.30
Cost difference	$4,363,906,773.41	$4,587,536,589.17	$4,822,626,387.25	$5,069,763,438.16	$5,329,565,107.28	$5,602,680,397.06	$5,889,791,568.31
Savings (with reduction factor)	$21,246,157.49	$22,334,923.71	$23,479,484.11	$24,682,697.87	$25,947,570.72	$27,277,262.38	$28,675,094.53

Figure 0-11. Calculations of savings to the users

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Car Costs

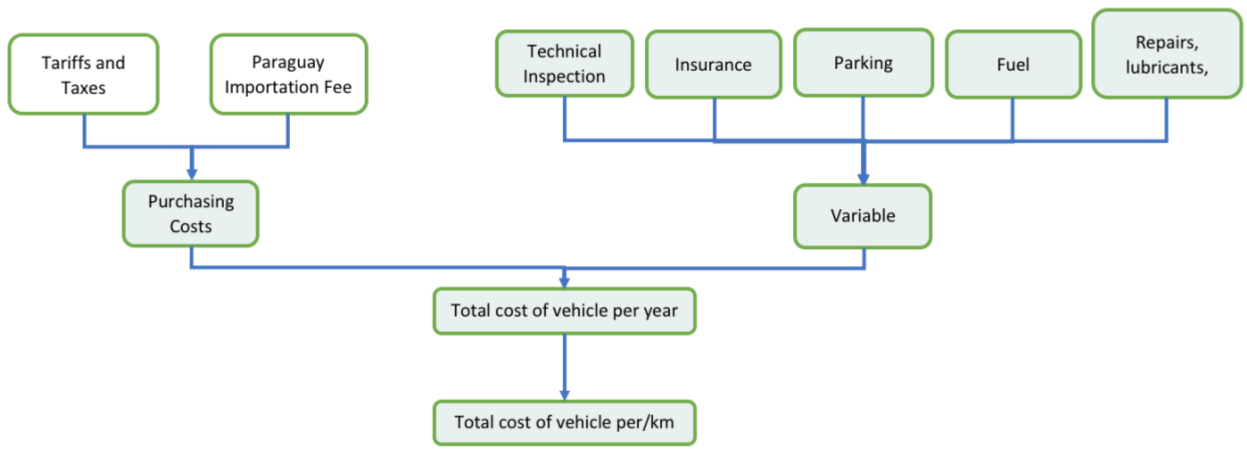

Figure 0-12. General components of the car cost calculation

This tab is used to calculate the annualized cost that owners have to pay for their cars, assuming they have a life of 11 years. It was based on a study made for transportation costs in Chile in 1997, and updated to present cost using the CPI for 1997 and 2017. The values used are for a 1500cc car, and consist of the value at import, and an 11% importation tariff, an 18% sales tax, a cylinder tax, and a 25% importation fee to Paraguay. We assumed there was a depreciation rate of 15%, which ended up resulting in a $3315 per year. To this we added yearly fees that consist of a technical inspection, insurance, parking spaces (which assumes 6 hours of parked time based on the controlled hours, which go from 7am to 1pm, and 3pm to 7pm), 260 working days, and fuel cost (this is calculated in the "Fuel Cost" tab). This results in the total cost of $5806 per car per year.

We then determined the yearly car volume going through Eusebio Ayala Avenue (the avenue in which the BRT runs through) based on a study done for the BRT in 2011, in the direction going towards Asunción (towards Centro) and towards San Lorenzo (away from Centro), and brought to 2017 based on the population growth. Based on the annual cost of the ownership of a car and the average distance of the trips (9.4km/way * 2 roundtrip) calculated in the "Public Transportation Costs" multiplied times 260 (working days) to make it the average yearly distance, we calculated the car cost per km, which ended up being $0.77. To this we added more costs that include repairs, lubricants, tires, and labor done on the car, which ended up being a total cost of $0.85 per kilometer.

Car Import Cost[1]	
	1500cc
Value at import	$6,500
11% Tariff	$715.00
18% Sales Tax	$1,298.70
Cylinder Tax	$587.00
Total (1997)	$9,101
Total (2017)	$13,880.13
25% Paraguay Importation Fee [2]	$3,470.03
Total Cost	$17,350.16
Depreciation rate	15%
Lifetime	11
Annualized Capital cost	($3,315.08)

CPI 1997	160.50
CPI 2017	244.79
Guarani/USD	5555.00

Annual Tariffs	
Ivesur Car (Technical inspection)	$46.62
Ivesur Motorcycle	$15.66
Insurance (3% of total imported car cost)	$520.50
Parking spaces ($)	$0.54
Parked Time (Hours)[3]	6
Number of days[4]	260.71
Total Parking/Year	$844.80
Total Fuel cost	$900.91
Total variable cost per car	$2,312.84
Total cost of vehicle per year	$5,627.92

Volume of cars at morning peak hour (6-8 am) in 2011[5]			
	# Cars	#Cars /hour (peak hour)	#Cars /hour (non-peak hour)
Volume towards Centro Point 1	2210.00	1105.00	994.50
Volume towards Centro Point 2	2340.00	1170.00	1053.00
Average	2275.00	1137.50	1023.75
Volume away from Centro Point 1	1315.00	657.50	591.75
Volume away from Centro Point 2	1240.00	620.00	558.00
Average	1277.50	638.75	574.88

Non peak hour reduction factor[6]
0.9

Car Volume (in Eusebio Ayala) (2017)[7]		
	Daily	Yearly
Towards centro	15667.79	5718744.65
Away from Centro	11167.07	4075981.82
Total (2017)[8]	26834.87	9794726.47

Number of kilometers per year per person [10]	6893.48
Car cost/km ($)	$0.82

Additional Costs per Kilometer [11]	
Repairs	0.04
Lubricants	0.00
Tires	0.02
Labor	0.02
Total car cost/km ($)	$0.89
Total passengers per vehicle[12]	1.61

Figure 0-13. Calculation of car cost per kilometer

Fuel Cost

In this table we calculated the average yearly cost of fuel per person. To do this, we first got information from Petropar, the national distributor of gasoline in Paraguay. This table provided us with the yearly sales in liters to each of the distributors, from which we were able to determine an average amount of gasoline sold per year. From Petropar we also got the yearly bonus to each of those distributors, however, we have not used that data. Based on the fuel cost per type of Petropar, we came up with an average cost per liter, which ended up being $0.83 per liter. From the demographics side, we used information gathered in the last census, which was held in 2012, and ha data regarding the percentage of population with a car and a motorcycle. We made an assumption here that a household either has a motorcycle or a car. This is not 100% true. The census also had data regarding average number of persons per household, which was 3.90, and from that we were able to determine the population with vehicles. The consumption of fuel per person per year ended up being $600.

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Guarani/USD	5555

Sale of Fuels by distributors (liters)[1]										
	2008	2009	2010	2011	2012	2013	2014	2015	Total	Average
B & R	145414915	127517710	129298920	176211460	153628980	147926120	117265900	99312010	1096576015	137072002
Petrobras	190568976	190695310	165642080	176474140	158808550	136178360	15437960		1033805376	147686482
Copetrol	128309383	92560790	99503530	131614260	111861260	98899820	66945500	50740500	780435043	97554380.4
Puma Energy	13439496	62402320	97843180	153065820	96194220	70372650	116522890	97947320	707787896	88473487
Esso	114784440	110054590	95288880	90461390	69913800	65675120	52956470		599134690	85590670
Axion Energy								33423220	33423220	33423220
Other	402695429	288743832	283226470	311563300	234322050	256518710	335878670	188887690		287729519
Total/year										877529760

Bonus by distributor (2008-2015)[1]			
	Total ($)	Span (years)	Total/Year
B & R	140273749	8	17534218.6
Petrobras	129319774	7	18474253.4
Copetrol	99937243	8	12492155.4
Puma Energy	91673243	8	11459155.4
Esso	75479764	7	10782823.4
Axion Energy	3313138	1	3313138
Others	757794874	3	252598291
Total/year			326654036

Fuel Cost (Guarani/L)[1]	
Diesel Type 1	5100
Diesel Type 3	4190
Nafta Econo 85	3890
Nafta Eco 90 Especial	4890
Nafta Ecoplus 95	5590
Ecoflex E85	4000
Average (G)	4610
Average ($)	$0.83

Fuel cost considered	1.245

Demographics and vehicles (2012)[2]	
Paraguay	6461041
Household with car	24.30%
Household with motorcycle	48.90%
Households with vehicle	73.20%
Average people/household	3.90
Population with vehicle	1212687.7

Consumption of fuel per capita per year	
Total Cost/person ($)	$900.91

Figure 0-14. Calculations for the yearly fuel expenditure per user

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Traffic Accidents Cost

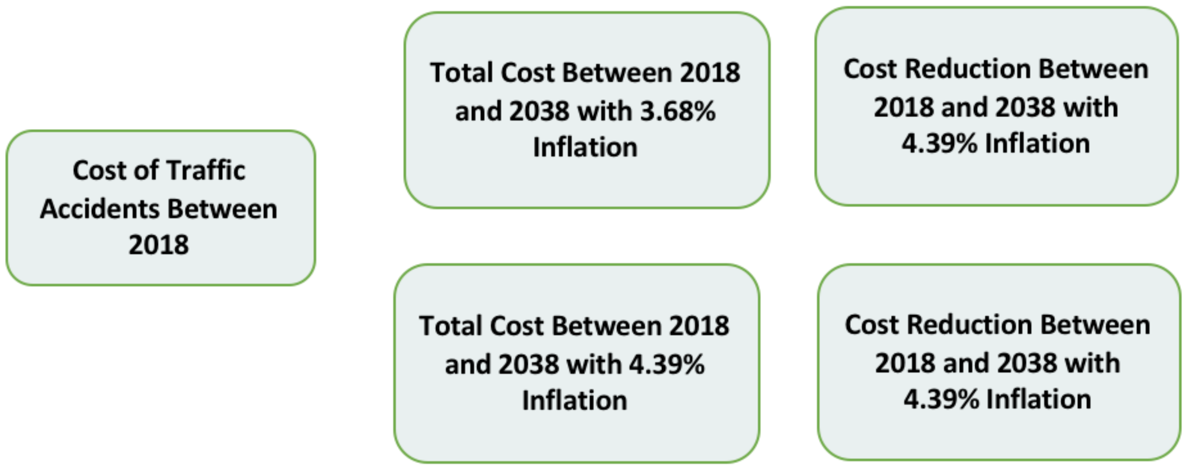

Figure 0-15. General components of accident savings

According to ABC Color, the Paraguayan capital, Asunción, suffered roughly 15,000 car accidents in 2015 with a cost of 70,000,000 Guarani ($12,600 using a $1=5,555.56 Guaranis exchange rate). This means that the total cost of accidents in 2015 was about $189 million ([70,000,000 Guarani / 5,555.56] * 15,000). Using an inflation rate of 3.68%, the team estimated the cost of these accidents for the next 50 years (2018 - 2068). The yearly cost of accidents can be achieved in 2 ways:

1. Using the "Future Value" formula in Microsoft Excel: select a 3.8% inflation as rate, one period (to move from 2017 to 2018 for example), no payment, and the value in the present year.
2. Multiplying yearly by a 1.0368 factor: since we want the yearly cost, we need to multiply the previous year's value by the inflation rate.

Another factor taken in consideration, is that the increase in accidents is equal to the assumed increase in cars, which would cause a surge in the number of cars by 1% yearly. After obtaining the future value of accident costs from 2018 to 2068 (See Table 1), the team determined that the total cost incurred in the next 50 years will be about $50.5 billion.

The table below is the scenario and costs that the team consider to be the most reasonable and probable. The inflation rates considered were the expected inflation for the next 5 years. Moreover, the cost of the accidents does not vary either, it only increases with the inflation, but the real value is the same.

The expected savings would be calculated by multiplying the costs by the expected number of cars reduced as a result of the Metro construction, which is about 0.49%. The calculation would be [Cost of Accident Year 2017 * Inflation Rate (3.68%) * Expected Car Increase (1%)) * Car Reducing Index (0.49%)]. The only factor that changes is the cost of accidents year. The sum of all these numbers is $241.4 million. Then this number is brought to the present using the "Net Present Value" formula with an 8% capitalization rate. This will give us a final savings number of $24 million. The table below shows all the calculations mentioned in this paragraph.

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Table 0-2. Accident Cost Forecast

Yearly Cost of Accidents	Cost with 3.68% Inflation
Cost of Accidents 2018	$219,592,481.85
Cost of Accidents 2019	$230,845,569.77
Cost of Accidents 2020	$242,675,325.83
Cost of Accidents 2021	$255,111,301.57
Cost of Accidents 2022	$268,184,562.93
Cost of Accidents 2023	$281,927,767.80
Cost of Accidents 2024	$296,375,247.65
Cost of Accidents 2025	$311,563,093.30
Cost of Accidents 2026	$327,529,245.02
Cost of Accidents 2027	$344,313,587.37
Cost of Accidents 2028	$361,958,048.77
Cost of Accidents 2029	$380,506,706.33
Cost of Accidents 2030	$400,005,895.85
Cost of Accidents 2031	$420,504,327.66
Cost of Accidents 2032	$442,053,208.25
Cost of Accidents 2033	$464,706,368.22
Cost of Accidents 2034	$488,520,396.71
Cost of Accidents 2035	$513,554,782.82
Cost of Accidents 2036	$539,872,064.15
Cost of Accidents 2037	$567,537,983.10
Cost of Accidents 2038	$596,621,651.03
Cost of Accidents 2039	$627,195,720.96
Cost of Accidents 2040	$659,336,569.01
Cost of Accidents 2041	$693,124,485.24
Cost of Accidents 2042	$728,643,874.19
Cost of Accidents 2043	$765,983,465.74
Cost of Accidents 2044	$805,236,536.77
Cost of Accidents 2045	$846,501,144.14
Cost of Accidents 2046	$889,880,369.70
Cost of Accidents 2047	$935,482,577.73
Cost of Accidents 2048	$983,421,685.70
Cost of Accidents 2049	$1,033,817,448.80
Cost of Accidents 2050	$1,086,795,759.12
Cost of Accidents 2051	$1,142,488,960.12
Cost of Accidents 2052	$1,201,036,177.27
Cost of Accidents 2053	$1,262,583,665.54
Cost of Accidents 2054	$1,327,285,174.79
Cost of Accidents 2055	$1,395,302,333.87
Cost of Accidents 2056	$1,466,805,054.31
Cost of Accidents 2057	$1,541,971,954.84
Cost of Accidents 2058	$1,620,990,807.56
Cost of Accidents 2059	$1,704,059,007.00
Cost of Accidents 2060	$1,791,384,063.25
Cost of Accidents 2061	$1,883,184,120.32
Cost of Accidents 2062	$1,979,688,501.08
Cost of Accidents 2063	$2,081,138,280.11
Cost of Accidents 2064	$2,187,786,885.96
Cost of Accidents 2065	$2,299,900,734.19
Cost of Accidents 2066	$2,417,759,892.91
Cost of Accidents 2067	$2,541,658,782.44
Cost of Accidents 2068	$2,671,906,910.73
Total	**$50,526,310,559.37**

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Table 0-3. Yearly savings from accidents

Yearly Cost of Accidents	Reduction 3.68%
Cost of Accidents 2018	$0.00
Cost of Accidents 2019	$0.00
Cost of Accidents 2020	$0.00
Cost of Accidents 2021	$0.00
Cost of Accidents 2022	$1,305,685.88
Cost of Accidents 2023	$1,372,596.18
Cost of Accidents 2024	$1,442,935.31
Cost of Accidents 2025	$1,516,879.00
Cost of Accidents 2026	$1,594,611.96
Cost of Accidents 2027	$1,676,328.36
Cost of Accidents 2028	$1,762,232.35
Cost of Accidents 2029	$1,852,538.52
Cost of Accidents 2030	$1,947,472.46
Cost of Accidents 2031	$2,047,271.32
Cost of Accidents 2032	$2,152,184.40
Cost of Accidents 2033	$2,262,473.79
Cost of Accidents 2034	$2,378,414.99
Cost of Accidents 2035	$2,500,297.64
Cost of Accidents 2036	$2,628,426.20
Cost of Accidents 2037	$2,763,120.75
Cost of Accidents 2038	$2,904,717.77
Cost of Accidents 2039	$3,053,570.98
Cost of Accidents 2040	$3,210,052.21
Cost of Accidents 2041	$3,374,552.38
Cost of Accidents 2042	$3,547,482.41
Cost of Accidents 2043	$3,729,274.29
Cost of Accidents 2044	$3,920,382.16
Cost of Accidents 2045	$4,121,283.42
Cost of Accidents 2046	$4,332,479.92
Cost of Accidents 2047	$4,554,499.26
Cost of Accidents 2048	$4,787,896.05
Cost of Accidents 2049	$5,033,253.34
Cost of Accidents 2050	$5,291,184.04
Cost of Accidents 2051	$5,562,332.48
Cost of Accidents 2052	$5,847,376.01
Cost of Accidents 2053	$6,147,026.69
Cost of Accidents 2054	$6,462,033.06
Cost of Accidents 2055	$6,793,182.04
Cost of Accidents 2056	$7,141,300.86
Cost of Accidents 2057	$7,507,259.14
Cost of Accidents 2058	$7,891,971.06
Cost of Accidents 2059	$8,296,397.68
Cost of Accidents 2060	$8,721,549.27
Cost of Accidents 2061	$9,168,487.89
Cost of Accidents 2062	$9,638,330.02
Cost of Accidents 2063	$10,132,249.37
Cost of Accidents 2064	$10,651,479.77
Cost of Accidents 2065	$11,197,318.31
Cost of Accidents 2066	$11,771,128.51
Cost of Accidents 2067	$12,374,343.81
Cost of Accidents 2068	$13,008,471.07
NPV	**$23,987,265.81**
Total	**$241,376,334.39**

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Air and Noise Pollution Costs

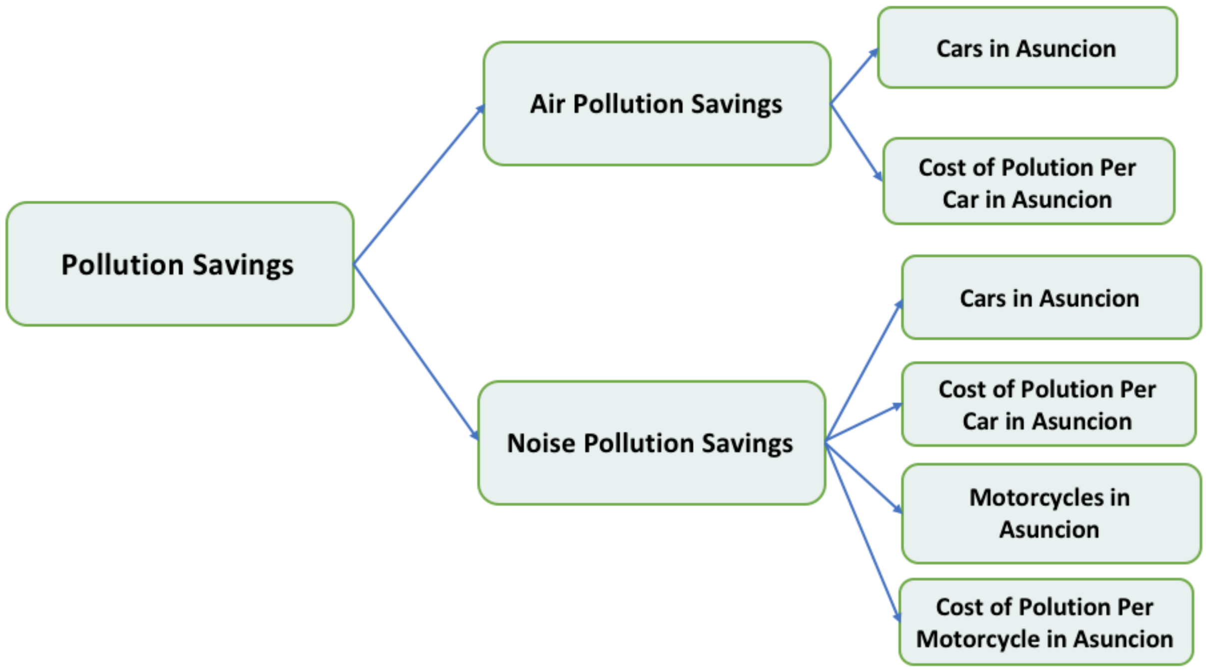

Figure 0-16. General components of air and noise savings

According to Zegras (1997), the cost per kilometer in 1997 of each car is between 0.022 - $0.04, which takes into consideration health and environmental impacts. The present value (2017) of these costs is between $0.03 - $0.06. The average commuting distance for people moving into the city and out of the city is 9.44 km in average. Taking this into consideration the round trip is 18.88 km, which would mean that having 260 working days would incur an annual cost of $164.76 - $314.54 per car, with an average of $239.65(Table 0-4.). The numbers shown in this table are the average of the ranges of costs.

The annual pollution cost per car for the next 50 years by doing an 18.88 km route for 260 days a year will be approximately $36.1 thousand (Table 0-5.). Using an 8% capitalization cost, the present value would be $4.2 thousand.

Table 0-4. Pollution cost in the USA for travelling 18.88km for 260 work days (2017)

Estimate Air Pollution Cost In the USA (Km)[1]	
Car Cost Criteria	
Cost Per Kilometer (1997)	$ 0.02
Cost Per Kilometer (2017)	$ 0.05
Round Trip Cost	$ 0.92
Annual Commute Cost	**$ 239.65**
Averge Annual Cost	**$ 239.65**

Table 0-5. Pollution cost in the USA for travelling 18.88km for 260 work days between 2018 and 2038

Forecast of Annual Air Pollution cost per vehicle	
Car Annual Trip Cost 2017	$ 239.65
Car Annual Trip Cost 2018	$248.47
Car Annual Trip Cost 2019	$257.61
Car Annual Trip Cost 2020	$267.09
Car Annual Trip Cost 2021	$276.92
Car Annual Trip Cost 2022	$287.11
Car Annual Trip Cost 2023	$297.68
Car Annual Trip Cost 2024	$308.64
Car Annual Trip Cost 2025	$319.99
Car Annual Trip Cost 2026	$331.77
Car Annual Trip Cost 2027	$343.98
Car Annual Trip Cost 2028	$356.64
Car Annual Trip Cost 2029	$369.76
Car Annual Trip Cost 2030	$383.37
Car Annual Trip Cost 2031	$397.48
Car Annual Trip Cost 2032	$412.10
Car Annual Trip Cost 2033	$427.27
Car Annual Trip Cost 2034	$442.99
Car Annual Trip Cost 2035	$459.29
Car Annual Trip Cost 2036	$476.20
Car Annual Trip Cost 2037	$493.72
Car Annual Trip Cost 2038	$511.89
Car Annual Trip Cost 2039	$530.73
Car Annual Trip Cost 2040	$550.26
Car Annual Trip Cost 2041	$570.51
Car Annual Trip Cost 2042	$591.50
Car Annual Trip Cost 2043	$613.27
Car Annual Trip Cost 2044	$635.84
Car Annual Trip Cost 2045	$659.23
Car Annual Trip Cost 2046	$683.49
Car Annual Trip Cost 2047	$708.65
Car Annual Trip Cost 2048	$734.73
Car Annual Trip Cost 2049	$761.76
Car Annual Trip Cost 2050	$789.80
Car Annual Trip Cost 2051	$818.86
Car Annual Trip Cost 2052	$849.00
Car Annual Trip Cost 2053	$880.24
Car Annual Trip Cost 2054	$912.63
Car Annual Trip Cost 2055	$946.22
Car Annual Trip Cost 2056	$981.04
Car Annual Trip Cost 2057	$1,017.14
Car Annual Trip Cost 2058	$1,054.57
Car Annual Trip Cost 2059	$1,093.38
Car Annual Trip Cost 2060	$1,133.61
Car Annual Trip Cost 2061	$1,175.33
Car Annual Trip Cost 2062	$1,218.58
Car Annual Trip Cost 2063	$1,263.43
Car Annual Trip Cost 2064	$1,309.92
Car Annual Trip Cost 2065	$1,358.13
Car Annual Trip Cost 2066	$1,408.10
Car Annual Trip Cost 2067	$1,459.92
Car Annual Trip Cost 2068	$1,513.65
Total	$ 36,133.12

To determine the cost of the pollution, we first need to know the total amount of cars in Asunción, since we already have the pollution cost by car. There was no information regarding the number of cars in Asunción, there was only information about number of cars in Paraguay. Since the information was limited, the team had to assume that the car distribution in the country was equal amongst its population. To calculate the total amount of cars in Asunción, we first divided the total amount of inhabitants in Asunción by Paraguay's population. We then multiplied this number by the total amount of cars in the country. This calculation would mean that the population distribution is the same as the car distribution, which would mean that Asunción would possess 32% of the cars in Paraguay since 32% of its population lives in Asunción. The team assumed that the yearly car growth is the same as the population growth rate, in order to perform a 50-year analysis to determine the number of cars in Asunción between 2018 and 2068 (Table 0-6.).

Table 0-6. Expected amount of car in Asunción between 2018 and 2068

Forcast Amount of Cars in Asuncion 2018 to 2068	
Year	Cars
2018	345,922
2019	350,741
2020	355,628
2021	360,583
2022	365,607
2023	370,701
2024	375,865
2025	381,102
2026	386,412
2027	391,796
2028	397,254
2029	402,789
2030	408,401
2031	414,091
2032	419,860
2033	425,710
2034	431,641
2035	437,655
2036	443,753
2037	449,936
2038	456,204
2039	462,561
2040	469,005
2041	475,540
2042	482,165
2043	488,883
2044	495,694
2045	502,601
2046	509,603
2047	516,703
2048	523,902
2049	531,202
2050	538,603
2051	546,107
2052	553,716
2053	561,430
2054	569,252
2055	577,184
2056	585,225
2057	593,379
2058	601,646
2059	610,029
2060	618,528
2061	627,146
2062	635,884
2063	644,743
2064	653,726
2065	662,834
2066	672,069
2067	681,433
2068	690,927

The cost of pollution, previously mentioned, per car is multiplied by the number of cars in the city. This will give us the approximate total cost cars will represent due to air pollution. But, since this cost is what it would cost in the USA, the team still needs to bring that to the reality of Paraguay. To do this, the team proceeded by dividing Paraguay's minimum wage by USA's minimum wage, which provided a reducing factor taking into consideration the general cost of life in Paraguay compared to that of in USA (368 PYG/$1256.67 = 0.2928). This reducing factor was multiplied by the air pollution costs of the next 50 years to determine the cost of car pollution in Paraguay (Table 0-7.). The team decided to do this because minimum wage is a number that reflects the cost of living and cost of services and goods in a country, therefore the team used it as a way to compare the costs in the USA versus the costs in Paraguay. The total cost of air pollution cost is approximately $19.8 billion.

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Table 0-7. Pollution cost in Asunción for average commuter between 2018 and 2068

Total Cost of Air Pollution In Asuncion	
Cost of Cars 2018	$85,951,464.97
Cost of Cars 2019	$90,356,075.63
Cost of Cars 2020	$94,986,401.98
Cost of Cars 2021	$99,854,010.91
Cost of Cars 2022	$104,971,062.04
Cost of Cars 2023	$110,350,338.10
Cost of Cars 2024	$116,005,276.91
Cost of Cars 2025	$121,950,004.90
Cost of Cars 2026	$128,199,372.39
Cost of Cars 2027	$134,768,990.74
Cost of Cars 2028	$141,675,271.31
Cost of Cars 2029	$148,935,466.47
Cost of Cars 2030	$156,567,712.68
Cost of Cars 2031	$164,591,075.81
Cost of Cars 2032	$173,025,598.79
Cost of Cars 2033	$181,892,351.63
Cost of Cars 2034	$191,213,484.10
Cost of Cars 2035	$201,012,281.01
Cost of Cars 2036	$211,313,220.44
Cost of Cars 2037	$222,142,034.85
Cost of Cars 2038	$233,525,775.36
Cost of Cars 2039	$245,492,879.34
Cost of Cars 2040	$258,073,241.44
Cost of Cars 2041	$271,298,288.27
Cost of Cars 2042	$285,201,056.91
Cost of Cars 2043	$299,816,277.43
Cost of Cars 2044	$315,180,459.65
Cost of Cars 2045	$331,331,984.37
Cost of Cars 2046	$348,311,199.20
Cost of Cars 2047	$366,160,519.40
Cost of Cars 2048	$384,924,533.79
Cost of Cars 2049	$404,650,116.17
Cost of Cars 2050	$425,386,542.41
Cost of Cars 2051	$447,185,613.53
Cost of Cars 2052	$470,101,785.10
Cost of Cars 2053	$494,192,303.31
Cost of Cars 2054	$519,517,347.93
Cost of Cars 2055	$546,140,182.66
Cost of Cars 2056	$574,127,313.17
Cost of Cars 2057	$603,548,653.26
Cost of Cars 2058	$634,477,699.44
Cost of Cars 2059	$666,991,714.61
Cost of Cars 2060	$701,171,921.01
Cost of Cars 2061	$737,103,703.16
Cost of Cars 2062	$774,876,821.12
Cost of Cars 2063	$814,585,634.75
Cost of Cars 2064	$856,329,339.39
Cost of Cars 2065	$900,212,213.69
Cost of Cars 2066	$946,343,880.09
Cost of Cars 2067	$994,839,578.68
Cost of Cars 2068	$1,045,820,455.04
Total Cost of Air Pollution	**$19,776,680,529.36**

The cost of noise pollution per kilometer per car in the city of Santiago in Chile was about $0.0014, and motorcycles $0.0069 in 1997. These costs brought to 2017 would be equal to $0.0029 and $0.014.

Table 0-8. Cost of Noise Pollution in Santiago de Chile 1997 and 2017

Cost of Noise Pollution Per Kilometer		
Cost	Cost 1997	Cost 2017
Cars Per Km	$ 0.0014	$ 0.0029
Motorcycles Per Km	$ 0.0069	$ 0.0142

To determine the cost of noise pollution in Asunción, we need to do the same reducing factor used in the air pollution section, but this time using Chile's minimum wage. By dividing Paraguay's minimum wage by Chile's, we obtain a reducing factor of 0.899756 (Table 0-8.).

The team then took the noise pollution cost of cars and motorcycles per kilometers to every year from 2018 to 2068 using a 3.68% inflation rate. Afterwards, these numbers were multiplied by 260 working days and the distance traveled each day in average (18.88 km). These numbers then multiplied by the number of cars and motorcycles gives us the total cost of cars and motorcycles (Table 0-9. and Table 0-10.). The sum of these two values gives us the total noise pollution cost range (Table 0-11.).

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Table 0-9. Car Cost Noise Pollution

Forecast of Total Car Noise Pollution Cost Between 2018 and 2038	
Yearly Cost of Noise Pollution	**Annual Trip Cost**
Cost of Car Noise 2018	$5,079,483.71
Cost of Car Noise 2019	$5,339,783.50
Cost of Car Noise 2020	$5,613,422.44
Cost of Car Noise 2021	$5,901,084.09
Cost of Car Noise 2022	$6,203,487.05
Cost of Car Noise 2023	$6,521,386.76
Cost of Car Noise 2024	$6,855,577.33
Cost of Car Noise 2025	$7,206,893.61
Cost of Car Noise 2026	$7,576,213.21
Cost of Car Noise 2027	$7,964,458.71
Cost of Car Noise 2028	$8,372,599.97
Cost of Car Noise 2029	$8,801,656.57
Cost of Car Noise 2030	$9,252,700.31
Cost of Car Noise 2031	$9,726,857.94
Cost of Car Noise 2032	$10,225,313.92
Cost of Car Noise 2033	$10,749,313.44
Cost of Car Noise 2034	$11,300,165.49
Cost of Car Noise 2035	$11,879,246.13
Cost of Car Noise 2036	$12,488,001.95
Cost of Car Noise 2037	$13,127,953.65
Cost of Car Noise 2038	$13,800,699.89
Cost of Car Noise 2039	$14,507,921.22
Cost of Car Noise 2040	$15,251,384.34
Cost of Car Noise 2041	$16,032,946.47
Cost of Car Noise 2042	$16,854,560.01
Cost of Car Noise 2043	$17,718,277.39
Cost of Car Noise 2044	$18,626,256.25
Cost of Car Noise 2045	$19,580,764.79
Cost of Car Noise 2046	$20,584,187.42
Cost of Car Noise 2047	$21,639,030.77
Cost of Car Noise 2048	$22,747,929.91
Cost of Car Noise 2049	$23,913,654.94
Cost of Car Noise 2050	$25,139,117.93
Cost of Car Noise 2051	$26,427,380.17
Cost of Car Noise 2052	$27,781,659.83
Cost of Car Noise 2053	$29,205,339.98
Cost of Car Noise 2054	$30,701,977.09
Cost of Car Noise 2055	$32,275,309.84
Cost of Car Noise 2056	$33,929,268.55
Cost of Car Noise 2057	$35,667,984.90
Cost of Car Noise 2058	$37,495,802.34
Cost of Car Noise 2059	$39,417,286.87
Cost of Car Noise 2060	$41,437,238.50
Cost of Car Noise 2061	$43,560,703.21
Cost of Car Noise 2062	$45,792,985.55
Cost of Car Noise 2063	$48,139,661.92
Cost of Car Noise 2064	$50,606,594.49
Cost of Car Noise 2065	$53,199,945.81
Cost of Car Noise 2066	$55,926,194.26
Cost of Car Noise 2067	$58,792,150.20
Cost of Car Noise 2068	$61,804,972.97
Sum of Total Cost	**$1,168,744,787.61**

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Table 0-10. Motorcycle Cost Noise Pollution

Forecast of Total Motorcycle Noise Pollution Cost Between 2018 and 2038	
Yearly Cost of Noise Pollution	Annual Trip Cost
Cost of Motorcycle Noise 2018	$12,947,262.36
Cost of Motorcycle Noise 2019	$13,610,749.01
Cost of Motorcycle Noise 2020	$14,308,236.25
Cost of Motorcycle Noise 2021	$15,041,466.45
Cost of Motorcycle Noise 2022	$15,812,271.27
Cost of Motorcycle Noise 2023	$16,622,576.23
Cost of Motorcycle Noise 2024	$17,474,405.54
Cost of Motorcycle Noise 2025	$18,369,887.11
Cost of Motorcycle Noise 2026	$19,311,257.92
Cost of Motorcycle Noise 2027	$20,300,869.58
Cost of Motorcycle Noise 2028	$21,341,194.22
Cost of Motorcycle Noise 2029	$22,434,830.63
Cost of Motorcycle Noise 2030	$23,584,510.79
Cost of Motorcycle Noise 2031	$24,793,106.68
Cost of Motorcycle Noise 2032	$26,063,637.46
Cost of Motorcycle Noise 2033	$27,399,277.01
Cost of Motorcycle Noise 2034	$28,803,361.83
Cost of Motorcycle Noise 2035	$30,279,399.43
Cost of Motorcycle Noise 2036	$31,831,077.06
Cost of Motorcycle Noise 2037	$33,462,270.91
Cost of Motorcycle Noise 2038	$35,177,055.82
Cost of Motorcycle Noise 2039	$36,979,715.44
Cost of Motorcycle Noise 2040	$38,874,752.93
Cost of Motorcycle Noise 2041	$40,866,902.23
Cost of Motorcycle Noise 2042	$42,961,139.87
Cost of Motorcycle Noise 2043	$45,162,697.40
Cost of Motorcycle Noise 2044	$47,477,074.45
Cost of Motorcycle Noise 2045	$49,910,052.51
Cost of Motorcycle Noise 2046	$52,467,709.31
Cost of Motorcycle Noise 2047	$55,156,434.06
Cost of Motorcycle Noise 2048	$57,982,943.39
Cost of Motorcycle Noise 2049	$60,954,298.10
Cost of Motorcycle Noise 2050	$64,077,920.84
Cost of Motorcycle Noise 2051	$67,361,614.65
Cost of Motorcycle Noise 2052	$70,813,582.40
Cost of Motorcycle Noise 2053	$74,442,447.36
Cost of Motorcycle Noise 2054	$78,257,274.69
Cost of Motorcycle Noise 2055	$82,267,594.07
Cost of Motorcycle Noise 2056	$86,483,423.57
Cost of Motorcycle Noise 2057	$90,915,294.61
Cost of Motorcycle Noise 2058	$95,574,278.33
Cost of Motorcycle Noise 2059	$100,472,013.17
Cost of Motorcycle Noise 2060	$105,620,734.02
Cost of Motorcycle Noise 2061	$111,033,302.74
Cost of Motorcycle Noise 2062	$116,723,240.29
Cost of Motorcycle Noise 2063	$122,704,760.54
Cost of Motorcycle Noise 2064	$128,992,805.73
Cost of Motorcycle Noise 2065	$135,603,083.83
Cost of Motorcycle Noise 2066	$142,552,107.77
Cost of Motorcycle Noise 2067	$149,857,236.70
Cost of Motorcycle Noise 2068	$157,536,719.32
Sum of Total Cost	$2,979,051,857.89

Table 0-11. Total Cost of Noise Pollution

Total Noise Pollution Cost	
Motorcycle + Car Cost	$4,147,796,645.50

The expected car reduction in Asunción, according to "Plan Ceta", was expected to be 8.27% over the course of 17 years. This information helped the team calculate a reducing annual factor of 0.4869%. By multiplying this annual car reducing rate times the cost of type of pollution, the team was able to calculate the benefits of implementing public transportation in the city of Paraguay. These benefits can be seen in Table 0-12. Air pollution costs per kilometer per car below, portraying the cost reduction regarding air pollution, and Table 0-13. and Table 0-14. that reflect the noise pollution cost benefit from implementing this Metro system.

Table 0-12. Air pollution costs per kilometer per car

Forecast of Annual Air Pollution Car Costs Benefit			
	Lower Limit	Higher Limit	Average
Car Annual Trip Cost 2017	$ 0.80	$ 1.53	$ 1.17
Car Annual Trip Cost 2018	$ 0.83	$ 1.59	$ 1.21
Car Annual Trip Cost 2019	$ 0.86	$ 1.65	$ 1.26
Car Annual Trip Cost 2020	$ 0.90	$ 1.71	$ 1.30
Car Annual Trip Cost 2021	$ 0.93	$ 1.78	$ 1.35
Car Annual Trip Cost 2022	$ 0.97	$ 1.84	$ 1.41
Car Annual Trip Cost 2023	$ 1.00	$ 1.91	$ 1.46
Car Annual Trip Cost 2024	$ 1.04	$ 1.99	$ 1.51
Car Annual Trip Cost 2025	$ 1.08	$ 2.06	$ 1.57
Car Annual Trip Cost 2026	$ 1.12	$ 2.14	$ 1.63
Car Annual Trip Cost 2027	$ 1.16	$ 2.22	$ 1.69
Car Annual Trip Cost 2028	$ 1.21	$ 2.31	$ 1.76
Car Annual Trip Cost 2029	$ 1.25	$ 2.40	$ 1.82
Car Annual Trip Cost 2030	$ 1.30	$ 2.49	$ 1.89
Car Annual Trip Cost 2031	$ 1.35	$ 2.58	$ 1.97
Car Annual Trip Cost 2032	$ 1.40	$ 2.68	$ 2.04
Car Annual Trip Cost 2033	$ 1.46	$ 2.78	$ 2.12
Car Annual Trip Cost 2034	$ 1.51	$ 2.89	$ 2.20
Car Annual Trip Cost 2035	$ 1.57	$ 3.00	$ 2.28
Car Annual Trip Cost 2036	$ 1.63	$ 3.11	$ 2.37
Car Annual Trip Cost 2037	$ 1.69	$ 3.23	$ 2.46
Car Annual Trip Cost 2038	$ 1.75	$ 3.35	$ 2.55
Total	**$ 224,652,004.15**	**$ 428,881,098.84**	**$ 326,766,551.49**

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Table 0-13. Noise pollution cost per car per kilometer

Forecast of Car Noise Pollution Cost Benefit Between 2018 and 2038		
Yearly Cost of Noise Pollution	Cost with 3.8% Inflation	Cost with 4.39% Inflation
Cost of Noise Pollution in 2018	$0.07	$0.08
Cost of Noise Pollution in 2019	$0.08	$0.09
Cost of Noise Pollution in 2020	$0.08	$0.09
Cost of Noise Pollution in 2021	$0.08	$0.09
Cost of Noise Pollution in 2022	$0.09	$0.10
Cost of Noise Pollution in 2023	$0.09	$0.10
Cost of Noise Pollution in 2024	$0.09	$0.11
Cost of Noise Pollution in 2025	$0.10	$0.11
Cost of Noise Pollution in 2026	$0.10	$0.12
Cost of Noise Pollution in 2027	$0.10	$0.12
Cost of Noise Pollution in 2028	$0.11	$0.13
Cost of Noise Pollution in 2029	$0.11	$0.13
Cost of Noise Pollution in 2030	$0.11	$0.14
Cost of Noise Pollution in 2031	$0.12	$0.14
Cost of Noise Pollution in 2032	$0.12	$0.15
Cost of Noise Pollution in 2033	$0.13	$0.16
Cost of Noise Pollution in 2034	$0.13	$0.16
Cost of Noise Pollution in 2035	$0.14	$0.17
Cost of Noise Pollution in 2036	$0.14	$0.18
Cost of Noise Pollution in 2037	$0.15	$0.19
Cost of Noise Pollution in 2038	$0.15	$0.19
Total Cars' Cost for 20 Years in Asuncion	**$19,172,359.80**	**$23,026,310.94**

Table 0-14. Noise pollution cost per motorcycle per kilometer

Forecast of Motorcycle Noise Pollution Cost Benefit Between 2018 and 2038		
Yearly Cost of Noise Pollution	Cost with 3.8% Inflation	Cost with 4.39% Inflation
Cost of Noise Pollution in 2018	$0.36	$0.41
Cost of Noise Pollution in 2019	$0.37	$0.42
Cost of Noise Pollution in 2020	$0.39	$0.44
Cost of Noise Pollution in 2021	$0.40	$0.46
Cost of Noise Pollution in 2022	$0.42	$0.48
Cost of Noise Pollution in 2023	$0.43	$0.50
Cost of Noise Pollution in 2024	$0.45	$0.53
Cost of Noise Pollution in 2025	$0.47	$0.55
Cost of Noise Pollution in 2026	$0.49	$0.57
Cost of Noise Pollution in 2027	$0.50	$0.60
Cost of Noise Pollution in 2028	$0.52	$0.62
Cost of Noise Pollution in 2029	$0.54	$0.65
Cost of Noise Pollution in 2030	$0.56	$0.68
Cost of Noise Pollution in 2031	$0.59	$0.71
Cost of Noise Pollution in 2032	$0.61	$0.74
Cost of Noise Pollution in 2033	$0.63	$0.77
Cost of Noise Pollution in 2034	$0.66	$0.81
Cost of Noise Pollution in 2035	$0.68	$0.84
Cost of Noise Pollution in 2036	$0.71	$0.88
Cost of Noise Pollution in 2037	$0.73	$0.92
Cost of Noise Pollution in 2038	$0.76	$0.96
Total Motorcycles' Cost for 20 Years In Asuncion	**$48,869,055.67**	**$58,692,517.92**

Regarding traffic accident cost reduction, the team took a similar approach to that of the pollution cost assessment. The yearly traffic accident costs were multiplied by the factor of yearly car reduction to obtain the annual and total traffic accidents cost reduction (Table 0-15.). This procedure provides the economic benefit of implementing a public transportation system, such as a Metro, in the city of Asunción.

Table 0-15. Savings from accidents reduction

Forecast of Traffic Accidents' Yearly Cost (20 Years)				
Yearly Cost of Accidents	**Cost with 3.8% Inflation**	**Cost with 4.39% Inflation**	**Reduction 3.8%**	**Reduction 4.39%**
Cost of Accidents 2018	$211,374,949.71	$ 212,571,315.63	$1,029,102.06	$1,034,926.70
Cost of Accidents 2019	$219,407,197.80	$ 221,897,882.11	$1,068,207.94	$1,080,334.11
Cost of Accidents 2020	$227,744,671.31	$ 231,633,651.68	$1,108,799.84	$1,127,733.77
Cost of Accidents 2021	$236,398,968.82	$ 241,796,578.15	$1,150,934.24	$1,177,213.09
Cost of Accidents 2022	$245,382,129.64	$ 252,405,403.02	$1,194,669.74	$1,228,863.31
Cost of Accidents 2023	$254,706,650.56	$ 263,479,690.07	$1,240,067.19	$1,282,779.69
Cost of Accidents 2024	$264,385,503.29	$ 275,039,861.48	$1,287,189.74	$1,339,061.65
Cost of Accidents 2025	$274,432,152.41	$ 287,107,235.40	$1,336,102.95	$1,397,812.98
Cost of Accidents 2026	$284,860,574.20	$ 299,704,065.35	$1,386,874.87	$1,459,142.03
Cost of Accidents 2027	$295,685,276.02	$ 312,853,581.22	$1,439,576.11	$1,523,161.88
Cost of Accidents 2028	$306,921,316.51	$ 326,580,032.10	$1,494,280.00	$1,589,990.61
Cost of Accidents 2029	$318,584,326.54	$ 340,908,731.00	$1,551,062.64	$1,659,751.45
Cost of Accidents 2030	$330,690,530.95	$ 355,866,101.58	$1,610,003.02	$1,732,573.04
Cost of Accidents 2031	$343,256,771.12	$ 371,479,726.78	$1,671,183.14	$1,808,589.69
Cost of Accidents 2032	$356,300,528.43	$ 387,778,399.80	$1,734,688.10	$1,887,941.56
Cost of Accidents 2033	$369,839,948.51	$ 404,792,177.09	$1,800,606.25	$1,970,774.99
Cost of Accidents 2034	$383,893,866.55	$ 422,552,433.86	$1,869,029.28	$2,057,242.75
Cost of Accidents 2035	$398,481,833.48	$ 441,091,921.89	$1,940,052.40	$2,147,504.27
Cost of Accidents 2036	$413,624,143.15	$ 460,444,829.96	$2,013,774.39	$2,241,726.02
Cost of Accidents 2037	$429,341,860.59	$ 480,646,846.88	$2,090,297.81	$2,340,081.75
Cost of Accidents 2038	$445,656,851.29	$ 501,735,227.29	$2,169,729.13	$2,442,752.84
Total	**$6,610,970,050.88**	**$ 7,092,365,692.33**	**$32,186,230.86**	**$34,529,958.20**

Car Reduction Factor

This tab served as a quick calculation for the impact the implementation of a reliable public transportation system would have on the car usage. The information in it comes from Plan Ceta (1998), and it consists basically in an estimate of the car units with and without the implementation of a bus system for 2015. This was done in 1998. So, we made a ratio of these two estimates and divided by 17, the decrease per year.

Appendix C: Traffic Index Calculations

This Appendix shows the data used to determine the traffic index of the main cities of Asunción.

Saturday 10/7/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
12:00 A.M. (Free flow)	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	10.00	33.60	9.00	37.33
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	11.00	30.55	10.00	33.60
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	27.00	40.89	25.00	44.16
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	24.00	27.50	22.00	30.00
	Fdo de la Mora	-25.308793, -57.61555	-25.346342, -57.577912	7.20	6.00	12.00	30.00	13.00	27.69
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	7.00	29.14	8.00	25.50

Time and Distance travelled by car						
			From Centro		To Centro	
Hour of day	Street	Distance (km)	Time (min)	Speed (km/h)	Time (min)	Speed (km/h)
6:30 AM	Artigas	5.60	13.40	25.07	23.60	14.24
	España	5.60	20.00	16.80	19.80	16.97
	Mcal. Lopez	18.40	38.60	28.60	49.60	22.26
	Eusebio Ayala	11.00	31.40	21.02	37.20	17.74
	Fdo de la Mora	6.00	16.00	22.50	22.40	16.07
	Felix Bogado	3.40	8.20	24.88	10.80	18.89
12:30 PM	Artigas	5.60	17.20	19.53	12.00	28.00
	España	5.60	24.40	13.77	17.20	19.53
	Mcal. Lopez	18.40	46.00	24.00	43.60	25.32
	Eusebio Ayala	11.00	34.00	19.41	29.40	22.45
	Fdo de la Mora	6.00	15.80	22.78	17.20	20.93
	Felix Bogado	3.40	9.60	21.25	8.80	23.18
5:30 PM	Artigas	5.60	21.00	16.00	15.00	22.40
	España	5.60	29.33	11.45	23.50	14.30
	Mcal. Lopez	18.40	60.00	18.40	44.17	25.00
	Eusebio Ayala	11.00	40.83	16.16	34.17	19.32
	Fdo de la Mora	6.00	24.50	14.69	17.00	21.18
	Felix Bogado	3.40	10.17	20.07	9.83	20.75

Traffic Index					
Hour of day	Street	From Centro	To Centro	Average	Morning/Evening Peak
6:30 AM	Artigas	0.34	1.622222222	0.981111111	0.891701373
	España	0.818181818	0.98	0.899090909	
	Mcal. Lopez	0.42962963	0.984	0.706814815	
	Eusebio Ayala	0.308333333	0.690909091	0.499621212	
	Fdo de la Mora	0.333333333	0.723076923	0.528205128	
	Felix Bogado	0.171428571	0.35	0.260714286	
12:30 PM	Artigas	0.72	0.333333333	0.526666667	
	España	1.218181818	0.72	0.969090909	
	Mcal. Lopez	0.703703704	0.744	0.723851852	
	Eusebio Ayala	0.416666667	0.336363636	0.376515152	
	Fdo de la Mora	0.316666667	0.323076923	0.319871795	
	Felix Bogado	0.371428571	0.1	0.235714286	
5:30 PM	Artigas	1.1	0.666666667	0.883333333	1.1
	España	1.666666667	1.35	1.508333333	
	Mcal. Lopez	1.222222222	0.766666667	0.994444444	
	Eusebio Ayala	0.701388889	0.553030303	0.627209596	
	Fdo de la Mora	1.041666667	0.307692308	0.674679487	
	Felix Bogado	0.452380952	0.229166667	0.34077381	

Percentage of usage through time

Avenues	Year	Personal vehicles	Bus
Artigas	1984	67.7	32.3
	1998	91.7	8.3
España	1984	95.4	4.6
	1998	95.8	4.2
Mcal. Lopez	1984	98.3	1.7
	1998	92.6	7.4
E. Ayala	1984	70.3	29.7
	1998	77.6	22.4
Fdo. De la Mora	1984	90	10
	1998	91.7	8.3
J. F. Bogado	1984	84.3	15.7
	1998	89.7	10.3

1998

Avenues	Personal vehicles	Bus
Artigas	91.7	8.3
España	95.8	4.2
Mcal. Lopez	92.6	7.4
E. Ayala	77.6	22.4
Fdo. De la Mora	91.7	8.3
J. F. Bogado	89.7	10.3

1984

Avenues	Personal vehicles	Bus
Artigas	67.7	32.3
España	95.4	4.6
Mcal. Lopez	98.3	1.7
E. Ayala	70.3	29.7
Fdo. De la Mora	90	10
J. F. Bogado	84.3	15.7

Monday 10/2/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
6:30 AM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	16.00	21.00	22.00	15.27
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	24.00	14.00	20.00	16.80
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	43.00	25.67	45.00	24.53
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	32.00	20.63	35.00	18.86
	Fdo de la Mora	-25.308793, -57.61555	-25.346342, -57.577912	7.20	6.00	25.00	14.40	16.00	22.50
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	9.00	22.67	8.00	25.50

Monday 10/2/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
12:30 PM	Artigas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	España	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mcal. Lopez	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Eusebio Ayala	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Fdo de la Mora	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Felix Bogado	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Monday 10/2/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
5:30 PM	Artigas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	España	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mcal. Lopez	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Eusebio Ayala	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Fdo de la Mora	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Felix Bogado	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Tuesday 10/3/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
6:30 AM	Artigas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	España	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mcal. Lopez	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Eusebio Ayala	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Fdo de la Mora	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Felix Bogado	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Tuesday 10/3/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
12:30 PM	Artigas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42.00
	España	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19.76
	Mcal. Lopez	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27.60
	Eusebio Ayala	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24.44
	Fdo de la Mora	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.95
	Felix Bogado	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.55

Tuesday 10/3/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
5:30 PM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	23	16.00	17	21.00
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	27	12.00	25	16.80
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	55	20.83	19	24.00
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	36	16.92	30	20.00
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	28	13.85	18	20.00
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	12	18.55	10	20.40

Wednesday 10/4/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
6:30 AM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	15.00	22.40	23.00	14.61
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	25.00	13.44	19.00	17.68
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	43.00	25.67	46.00	24.00
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	33.00	20.00	33.00	20.00
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	23.00	15.65	17.00	21.18
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	10.00	20.40	7.00	29.14

Wednesday 10/4/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
12:30 PM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	18.00	18.67	6.00	56.00
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	22.00	15.27	16.00	21.00
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	39.00	28.31	41.00	26.93
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	32.00	20.63	29.00	22.76
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	16.00	22.50	17.00	21.18
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	11.00	18.55	9.00	22.67

Wednesday 10/4/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
5:30 PM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	21.00	16.00	16.00	21.00
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	28.00	12.00	20.00	16.80
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	53.00	20.83	46.00	24.00
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	39.00	16.92	33.00	20.00
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	26.00	13.85	18.00	20.00
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	11.00	18.55	10.00	20.40

Thursday 10/5/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
6:30 AM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	16.00	21.00	21.00	16.00
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	25.00	13.44	17.00	19.76
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	45.00	24.53	48.00	23.00
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	35.00	18.86	30.00	22.00
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	26.00	13.85	16.00	22.50
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	10.00	20.40	9.00	22.67

Thursday 10/5/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
12:30 PM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	19.00	17.68	14.00	24.00
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	23.00	14.61	15.00	22.40
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	43.00	25.67	42.00	26.29
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	36.00	18.33	29.00	22.76
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	15.00	24.00	16.00	22.50
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	9.00	22.67	9.00	22.67

Thursday 10/26/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
5:30 PM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	16.00	21.00	12.00	28.00
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	23.00	14.61	17.00	19.76
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	52.00	21.23	44.00	25.09
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	34.00	19.41	31.00	21.29
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	18.00	20.00	16.00	22.50
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	9.00	22.67	9.00	22.67

Friday 10/6/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
6:30 AM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	19.00	17.68	36.00	9.33
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	20.00	16.80	18.00	18.67
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	39.00	28.31	46.00	24.00
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	31.00	21.29	41.00	16.10
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	15.00	24.00	25.00	14.40
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	8.00	25.50	11.00	18.55

Friday 10/6/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
12:30 PM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	17.00	19.76	13.00	25.85
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	26.00	12.92	19.00	17.68
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	49.00	22.53	47.00	23.49
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	33.00	20.00	29.00	22.76
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	16.00	22.50	16.00	22.50
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	9.00	22.67	8.00	25.50

Wednesday 11/8/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
7:30 AM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	16.00	21.00	26.00	12.92
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	21.00	16.00	23.00	14.61
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	39.00	28.31	48.00	23.00
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	32.00	20.63	36.00	18.33
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	13.00	27.69	20.00	18.00
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	7.00	29.14	10.00	20.40

Wednesday 11/8/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
1:00 PM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	15.00	22.40	12.00	28.00
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	21.00	16.00	16.00	21.00
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	44.00	25.09	40.00	27.60
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	32.00	20.63	29.00	22.76
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	15.00	24.00	16.00	22.50
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	9.00	22.67	9.00	22.67

Wednesday 11/8/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
6:30 PM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	19.00	17.68	16.00	21.00
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	25.00	13.44	19.00	17.68
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	59.00	18.71	42.00	26.29
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	36.00	18.33	31.00	21.29
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	23.00	15.65	16.00	22.50
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	10.00	20.40	10.00	20.40

Thursday 11/9/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
6:30 AM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	11.00	30.55	20.00	16.80
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	16.00	21.00	16.00	21.00
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	33.00	33.45	51.00	21.65
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	28.00	23.57	38.00	17.37
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	14.00	25.71	24.00	15.00
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	8.00	25.50	13.00	15.69

Thursday 10/26/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
6:00 PM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	16.00	21.00	13.00	25.85
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	24.00	14.00	20.00	16.80
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	53.00	20.83	43.00	25.67
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	38.00	17.37	30.00	22.00
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	20.00	18.00	16.00	22.50
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	10.00	20.40	10.00	20.40

Friday 11/10/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
7:00 AM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	12.00	28.00	24.00	14.00
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	19.00	17.68	21.00	16.00
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	39.00	28.31	56.00	19.71
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	31.00	21.29	39.00	16.92
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	15.00	24.00	29.00	12.41
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	8.00	25.50	14.00	14.57

Friday 11/10/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
12:00 PM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	17.00	19.76	15.00	22.40
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	30.00	11.20	20.00	16.80
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	55.00	20.07	48.00	23.00
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	37.00	17.84	31.00	21.29
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	17.00	21.18	21.00	17.14
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	10.00	20.40	9.00	22.67

Friday 11/10/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
6:00 PM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	29.00	11.59	16.00	21.00
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	30.00	11.20	25.00	13.44
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	73.00	15.12	51.00	21.65
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	41.00	16.10	34.00	19.41
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	26.00	13.85	19.00	18.95
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	12.00	17.00	10.00	20.40

Thursday 11/9/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
7:00 AM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	12.00	28.00	24.00	14.00
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	19.00	17.68	20.00	16.80
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	38.00	29.05	47.00	23.49
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	30.00	22.00	39.00	16.92
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	16.00	22.50	25.00	14.40
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	10.00	20.40	13.00	15.69

Thursday 10/26/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km)	Actual Distance (km)	Time (min)	Speed	Time (min)	Speed
6:30 PM	Artigas	-25.283935, -57.621424	-25.252080, -57.578305	5.80	5.60	15.00	22.40	12.00	28.00
	España	-25.284048, -57.626659	-25.286368, -57.572481	8.80	5.60	24.00	14.00	20.00	16.80
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.510845	8.80	18.40	49.00	22.53	39.00	28.31
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.521473	6.60	11.00	35.00	18.86	31.00	21.29
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.577912	7.20	6.00	19.00	18.95	16.00	22.50
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.627070	3.40	3.40	10.00	20.40	10.00	20.40

Thursday 11/9/17						From Centro		To Centro	
Hour of day	Street	Centro	Afueras	Initial Distance (km	Actual Distance (k	Time (min)	Speed	Time (min)	Speed
7:00 PM	Artigas	-25.283935, -57.621424	-25.252080, -57.5783	5.80	5.60	17.00	19.76	12.00	28.00
	España	-25.284048, -57.626659	-25.286368, -57.5724	8.80	5.60	23.00	14.61	21.00	16.00
	Mcal. Lopez	-25.277073, -57.638655	-25.337029, -57.5108	8.80	18.40	55.00	20.07	42.00	26.29
	Eusebio Ayala	-25.299743, -57.621379	-25.339772, -57.5214	6.60	11.00	33.00	20.00	29.00	22.76
	Fdo de la Mora	-25.308793, -57.615551	-25.346342, -57.5779	7.20	6.00	20.00	18.00	15.00	24.00
	Felix Bogado	-25.296796, -57.631852	-25.327838, -57.6276	3.40	3.40	10.00	20.40	9.00	22.67